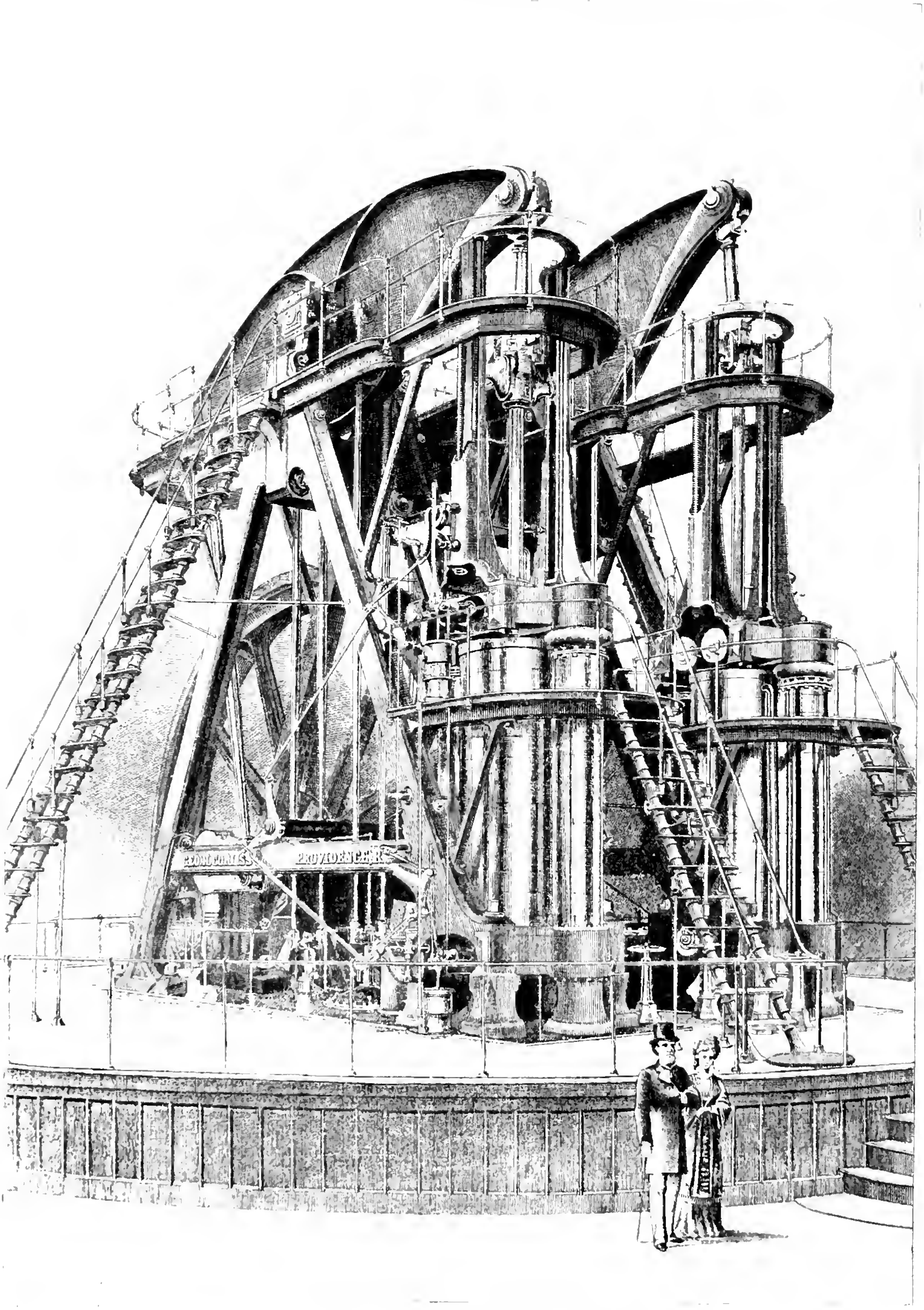

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THE

ICONOGRAPHIC ENCYCLOPÆDIA

APPLIED MECHANICS

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PREFACE.

THIS volume embodies a compendious presentation of APPLIED MECHANICS through a consideration of such typical appliances as come within the scope of the plan formulated in its Table of Contents and its Introductory pages.

In the treatment of so broad a subject, ramifying as it does into every avenue of human activity, and in view of the fact that mechanical appliances form a concomitant of every phase of the struggle by which man has acquired mastery over the materials and forces of Nature, these appliances must manifestly be considered in accordance with some definite arrangement, and from some standpoint which shall enable us to grasp all the salient elements of the subject. The task of the authors and editors, therefore, has largely been that of selecting, from a redundancy of matter, such material as would logically fall within the scope of the volume.

Many reasons might be advanced for varying, more or less, both the range and the details of treatment of the subject-matter; but the inclusion of any given appliance to the exclusion of any other has been determined with regard not only to the plan of the work, but also to the applicability of any specified mechanism in elucidating the topic under discussion. A variety of machines not considered in this volume—for example, printing and paper-making machinery, electrical appliances, etc.—will be more appropriately treated in other volumes of the series.

The following pages present in clear and definite outline an account of the origin, development, construction, purposes, and effects of wood- and metal-working tools and machines; of motors; of appliances for the transport of solids, liquids, and gases; of measuring apparatus; and of textile, flouring, grinding, and agricultural machinery. In this it is intended to serve the needs of the general reader, and also to afford both the practical mechanic and the technologist opportunity for suggestive study.

The work itself, while in part a popular amplification of the well-known practical treatise on *Mechanischen Technik*, by the distinguished German professors Hartig and Weiss, in the "Bilder-Atlas," is based on a plan originally outlined for it by the American editors. While the translated text and the illustrative material of the original work have been utilized wherever consistent with the general scheme, its several divisions have been elaborated by specialists of acknowledged ability. Both the text and the illustrations as found in the original treatise have been greatly extended, and no effort has been spared to render the work as perfect as it is unique. While in its modern examples and illustrations it is thoroughly and representatively American, it gives the salient features of European practice where that practice differs from the methods adopted on this side of the Atlantic.

Acknowledgment is hereby tendered the numerous mechanicians, inventors, and manufacturers (many of them of world-wide fame) to whom the editors and publishers are indebted for much valuable material. Through the aid of these efficient collaborators there have been included many details of special interest not heretofore published, and the subject-matter has been presented with a thoroughness and an aptness which otherwise would not have been attainable.

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APPLIED MECHANICS.

PART I.—TECHNOLOGY.

APPLIED MECHANICS.

INTRODUCTORY.

THE various applications of the natural forces to the requirements of man are included under the general term of Technics, which is divided into two main subdivisions—namely, Chemical Technics and Mechanical Technics.

While it is the province of Agriculture and of Forestry, as well as of Mining, to gain from nature the substances available for useful requirements, and, besides utilizing its stores, to direct its processes for the purpose of more fruitful production, the chief objects of Technics are the conversion of the crude products thus obtained into articles of use, and the transportation and distribution of these articles.

Like all other branches of science, which by reason of the increasing mass and variety of material subdivide and ramify in various directions, the general field of Technics is divided into the specific departments of Technology and Technics proper, the former relating to the science of industrial processes, the latter to their practical application.

Chemical Technics embraces the various means and processes by which raw materials are converted into available condition by chemical action, thus constituting the department of Applied Chemistry.

Mechanical Technics deals with the means and appliances by which such crude products are fabricated into useful forms and transported from place to place, thus constituting the department of Applied Mechanics.

To a material extent all the methods by which the nascent products of nature are primarily obtained include in varying degrees the elements of both Chemical and Mechanical Technics. Various functions of all these methods are effected to the best advantage by the application of mechanical means, and such mechanisms may properly be included in a consideration of the subject of Applied Mechanics. The present treatise, however, is restricted to a review of typical mechanisms whose operations are purely mechanical, and whose functions are wholly independent of chemical processes.

Generally considered, the department of Applied Mechanics includes also the Technics of Engineering and Construction. These two branches, which deal chiefly with static force, may properly be embraced under the term "Static Technics," while that portion of Applied Mechanics which

deals primarily with force in motion may be designated "Dynamic Technics."

Latterly, all the different branches of Mechanics have been organized into a body of science termed Kinematics, which correlates the various phenomena of Mechanics and explains the relations between the specific motion and the form of construction requisite for the production of that motion. Apart, however, from these features of the subject, there yet remains that department of Applied Mechanics which deals primarily with the aims of fabrication, and with the means and appliances by which the various technical purposes are subserved.

It has, furthermore, become customary, mainly in view of the historic development of the subject, to assign to the Technics of Construction and Engineering an entirely separate position between Architecture and Mechanical Technics, and thus the latter subject, excluding the distinct branches of Naval and Military Technics as non-industrial, is limited to a definite field which may be specified as embracing the application of mechanical force to the change of shape, size, surface, temperature, configuration, and position of material substances. In producing these changes this force is brought into activity by means of appliances or tools.

The fabrication of tools is one of the most salient of the features that distinguish man from the rest of animate nature; for though many members of the brute creation utilize various organs as tools, and though apes are known to use stones as missiles and limbs of trees as weapons, yet man is the only animal that actually fashions implements for specific requirements, and that utilizes them as auxiliary agents in accomplishing desired ends.

These auxiliary agents are divided into two distinct classes—namely, hand-tools and machine-tools. The former are actuated directly by the human hand, and therefore require a certain degree of skill in conjunction with physical strength, while the latter are characterized by a definite limit of motion, and, though this motion may be produced by human strength, every available source of power may be substituted therefor. The rapid development of the civilized world during the nineteenth century has been directly due to the ever-increasing success with which hand-tools have become supplanted by machinery and muscular power by the force of moving water and air, by heat as applied through the steam-engine, and by chemical action as utilized through expansive gases evolved from explosives, by electricity, etc.

Through the application of these forces the capacity and facility of mechanical operations have been increased to such an extent that the ingenuity of inventors has during the past half century been chiefly directed to the development of mechanisms through which the natural forces are to be employed.

The application of such mechanisms, together with their construction, constitutes what is termed the Utilitarian or Industrial Arts, as distin-

guished from the Æsthetic or Fine Arts. In every branch of the Utilitarian arts mechanisms of a more or less complicated structure are applied in forms as varied as are the purposes to be subserved, and a consideration of these mechanisms forms the general subject of Applied Mechanics. The present treatise, therefore, is devoted to a description of a vast range of apparatus comprising the requisite appliances for effecting the successive changes in the condition and relation of materials, and for transforming them into the multitude of objects required by civilized man. Not the least important of these appliances are those constructed for the purpose of controlling the free forces of nature or of converting its latent forces into serviceable conditions.

Manual appliances, or hand-tools, have been developed, in the course of progress, from such primitive forms as the flints of the Palæolithic Period, the stone knives and stone saws of the Glacial or Stone Age, and the more perfected implements of the Bronze Epoch, to a stage where they have been gradually merged into the more complicated mechanisms known as machine-tools; hand-tools are therefore, in the main, to be considered as embodying the primary stage of technical development.

No classification of mechanical appliances can be made which will be so definite as distinctly to differentiate all the numerous forms of mechanism, yet in general they may be arranged into a number of classes, distinguished by the nature of the function for which the various appliances are designed. These several classes are the following—namely, Machine-tools, Prime-movers, Machines for Convection, Measuring-machines, and Special Appliances.

Machine-tools may be divided into two categories—namely, (1) those which deal with substances in their natural or crude form, and (2) those which are designed to manipulate the partially or fully prepared materials in the more advanced or final stages of fabrication.

The first category may be subdivided into three classes—namely, (1) appliances for compressing or crushing, (2) appliances for abrasion or grinding, and (3) appliances for incision or cutting.

The category of manipulating-machines must necessarily be subdivided according to the work for which the various machines are designed. The most important of these manipulating-tools are comprised in the following classes—namely, machines for agricultural purposes, machines for working wood and metals, machines for making textiles, etc.

Of the second subdivision, comprising prime-movers or machines for the production of mechanical force, through which motive power is evolved from muscular energy, from the force of moving air or water, or from heat or electricity, the following are the main class-divisions—namely, tread-mills, wind-wheels, water-wheels, steam-boilers, steam-engines, caloric or hot-air engines, gas-engines, and electric motors.

The third general subdivision of mechanical appliances comprises the various means (1) for the transportation of solids, (2) for the convection of liquids and gases, and (3) for the transmission of power. These may be

classified as follows—namely, (1) *a*, vehicles, *b*, hoisting-machines; (2) *a*, pumps, *b*, blowers and fans; and (3) *a*, gearing, *b*, shafting, *c*, pulleys, and *d*, belting.

The fourth general subdivision, that of measuring-machines, includes the various appliances for the measurement of weight, of time, and of other quantities. These consist of (1) scales, (2) timepieces, and (3) meters in general.

Finally, there is to be considered an extensive range of individual appliances, among which may be enumerated writing-machines, typesetting-machines, calculating-machines, and other machines designed for specific purposes.

PART I.

TECHNOLOGY.

I. MACHINES FOR CONVERTING RAW MATERIALS.

I. MILLS.

OF the various mechanical processes by which the condition of natural products is changed, that of pulverizing is the simplest; and the earliest human contrivances were doubtless of the nature of mills for crushing and grinding fruits and seeds.

The term *mill* was originally restricted to denote the various forms of apparatus by which grain is ground into flour or meal, and the equivalent word in the Latin and its allied languages still retains this signification (Lat. *mola;* It. *mulino;* Sp. *molino;* Fr. *moulin*). In modern English usage, however, the term is applied to nearly all machines and combinations of machinery which consist chiefly of wheel-work and its co-ordinate appliances, by which raw materials are changed into new forms and conditions; and the mill generally takes its name either from the principle of its action, as "rolling-mill," "saw-mill," or from the materials upon which it acts, as "cotton-mill," "corn-mill," and the like.

The present section will be chiefly devoted to the consideration of mills used for grinding grain. These will be considered under three divisions: (1) those comprising such mealing implements as are operated exclusively by hand: these have been employed from the earliest period of human history to the present time; (2) those in which one of a pair of stones is formed for continued rotary motion, and which may be driven by hand-, animal-, water-, or wind-power: such have also been employed during the greater part of historic time; and (3) those which combine in one system of connected machinery all the necessary contrivances for grinding, separating, cleaning, packing, and automatically moving the grain and meal from one part of the mill-house to another and to and from the several machines; also for receiving the grain from transports and for delivering the packed flour to the same. These mills have been perfected almost entirely within the present century. To these there is added a fourth division, which embraces mills constructed on principles similar to those employed

for grinding grain, and used not only for the reduction of substances to powder, but also for the crushing of olives, minerals, and ores, and for the comminuting and mixing of confections, drugs, chemicals, materials for paints, ceramics, etc. The mills of this class will be considered according to their mode of action—namely, (1) crushing and (2) grinding.

1. MEALING IMPLEMENTS OPERATED BY HAND.

From the earliest historic periods to the present, the edible grains have been ground between two stones. The original grinding implement was a fixed stone, in a hollowed-out portion of which the grain was pounded with a boulder in the hand. If such a crude device is worthy the name of *mill*, then, indeed, corn-mills have the highest antiquity.

Primitive Mills.—Dr. Schliemann, in his *Ilios*, makes mention of certain rudely-cut, nearly globular stone instruments which he found in great numbers in all the four lower prehistoric cities, and of which he says he could have collected thousands. They are of basaltic lava, granite, quartz, diorite, porphyry, or other hard and gritty stone, and in rare instances of silex. Similar implements are found in the cave-dwellings of France, and are numerous in the most ancient Swiss lake-habitations. In the opinion of Professor Lindenschmitt, these implements, which are of the simplest kind, were the most ancient millstones, and were employed for bruising the grain on the slabs of sandstone which abound in the lake-habitations. The fact that these stones occur in considerable numbers in the *ténevières*, many of them having a diameter of 24 inches, indicates that the grain was triturated by means of rounded pestles (*pl.* 1, *fig.* 1). These, as well as the millstones, were of granite or grit, and never of limestone.

It was scarcely to be expected that the products of these primitive contrivances would be discovered, but in Eastern Switzerland there have been found the remains of bread which has been preserved by carbonization (Desor). Three varieties of wheat, two of barley, and two of millet were cultivated by the lake-dwellers.

At Wauwyl, in the canton of Lucerne, many corn-crushers have been found in the villages of the Stone Age; these are balls of hard stone 2 or 3 inches in diameter (Lubbock). Round corn-bruisers were also found in the *débris* of the Stone Age of Egypt. Stone balls for bruising corn are utilized by the Indians of the Yosemite Valley, in California. Their squaws pound acorns with round-stone mullers on a granite rock, whose flat surface is worn into holes by the operation. These stationary mortars ("potholes") are abundant in other parts of the State.

Dr. Schliemann, quoting Helbig, remarks that "tradition has ever preserved a trace of the fact that there existed no proper apparatus for grinding at the time of the oldest Italic development, inasmuch as the *mola versatilis*—the most perfect apparatus, whose upper part was turned by a handle above the lower one—was, according to Varro, an invention of the Volsinians. This tradition, therefore, presupposed an older epoch,

during which people utilized other more imperfect means, possibly with two stones, such as were used by the ancient inhabitants of the *terramare* villages for pounding the grains."

In Biblical history evidences are not wanting of the early existence of means for reducing the cereals to powder, and we may conclude that when Abraham hastened into the presence of Sarah, saying, "Make ready quickly three measures of fine meal, knead it, and make cakes" (Gen. xviii. 6), there must have existed some sort of mill for rapidly grinding grain into flour, and to meet the demand for "fine meal" it is evident that there was used a more efficient implement than the mill above described.

The literature of ancient decorticating- and grinding-mills and of their details of construction is exceedingly meagre. Early writings give results without mentioning the means employed for obtaining them. These mills, however, were probably like the mill shown in Figure 2 (*pl.* 1), which was sent to England by Dr. Livingstone from the banks of the Shire, in South Africa. This mill comprises an upper stone and a fixed nether stone with a hollow upper surface, in which the corn was ground by the action of the upper stone moved upon the lower by hand.

"The mill consists of a block of granite, syenite, or even mica schist, 15 or 18 inches square and 5 or 6 inches thick, with a piece of quartz or other hard rock about the size of a half-brick, one side of which has a convex surface and fits into a hollow in the larger and stationary stone. The operator, kneeling (*fig.* 3), grasps the upper millstone with both hands and works it backward and forward in the hollow of the lower millstone in the same way that a baker works his dough when pressing it and pushing it from him. The weight of the person is brought to bear on the movable stone, and while it is pressed and pushed forward and backward one hand supplies, every now and then, a little grain, to be thus at first bruised and then ground on the lower stone, which is placed on the slope; so that the meal, when ground, falls on a skin or mat spread out for the purpose."

The Kaffirs and other natives of Africa use a similar mill, consisting of a large stone slightly hollowed on its upper surface, and of a muller formed of a large oval pebble, which is used with a peculiar rocking and grinding motion. In Abyssinia the grain is reduced to flour on a similar nether stone by repeated grinding or rolling with a stone rolling-pin. Such mealing-stones are also in use in South America. They have occasionally been found in Great Britain and in Ireland.

Livingstone, in his *Zambezi and its Tributaries*, gives the following description of the method of preparing the grain and the manner of grinding it: "The corn is pounded in a large wooden mortar like the ancient Egyptian one (*fig.* 4), with a pestle 6 feet long and about 4 inches thick. The pounding is performed by two or three women at one mortar. Each, before delivering a blow with her pestle, gives an upward jerk of the body, so as to put strength into the stroke; and they keep exact time, so that two pestles are never in the mortar at the same moment. The measured

thud, thud, thud of the women standing at their vigorous work are associations inseparable from a prosperous African village. By the operation of pounding, with the aid of a little water, the hard outside husk of the grain is removed and the corn is made fit for the millstone" (*pl.* 1, *fig.* 2).

"The same form of pestle and mortar for cleaning grain of its husks is met with from Egypt to the southern extremity of the continent of Africa. The existence of this seems to show that the same want has been felt and provided for from the period of the earliest migrations of this people."

Pot-holes.—Dr. C. C. Abbott, in his elaborate article on the *Stone Age in New Jersey*, says, "The Indian women, upon whom fell all the drudgery of aboriginal life, reduced the hard kernels of maize to coarse meal by pounding them in hollows of rocks, natural or artificial, with globular pebbles, or with long cylindrical stones, carefully chipped for the purpose, and known as pestles. Wooden mortars and pestles were also used.

"In the northern section of the State, where rocks *in situ* abound, deep basins hollowed in immovable rocks are very numerous, which is evidence that in the rocky sections of the State the site of a village was chosen with reference to the 'mill,' while in the southern part, where rocks suitable for mills do not exist, are found stones weighing twenty or more pounds, which were brought from a distance; a receptacle was first chipped on one side, which gradually by use became both deep and smoothly worn."

The stationary mortars are generally larger in diameter and of greater depth than the portable examples, and could be used only with the long pestles. The vast majority of these stationary mortars are natural "potholes," possibly in some cases deepened intentionally, or by long usage in crushing corn. Such a pot-hole used as a mortar formerly existed in a large glacial boulder in Centre street, Trenton, New Jersey (*fig.* 5). When excavations were made to remove this rock, several broken pestles were brought to light, besides a stone axe and several dozens of spear- and arrow-heads of various sizes. It is said that the present site of Trenton was the headquarters of a great chief; here the small portable corn-mills are abundant, and they were probably used solely in reducing grain to meal. Hereabouts have been found hundreds of pestles, many of which may be seen in private collections; they are cylindrical water-worn pebbles such as abound in the bed of the Delaware River at this place.

The "knockin'-stane" consists of a large stone, often a boulder, with a cup-like excavation on one side. It is found in common use in Shetland, and is occasionally employed in many other parts of Scotland. The barley, after being well dried, is placed in the excavation, and is then struck repeatedly and steadily with a wooden mallet. As the blows fall, many of the grains start out, but they are constantly put back by a woman or child who sits opposite the man wielding the mallet. The *knockin'-stane* (*fig.* 6) is a rude implement, but in making pot-barley it does work of fair quality (Mitchell).

Metates.—Figure 9 (*pl.* 1) illustrates a Mexican machine for grinding—or, rather, mashing—corn for *tortillas*. The grain is first soaked in lime-water containing a small quantity of crude soda until the hull separates from the kernel; it is then placed in proper quantities on the *metate*, which is a stone of black porphyry about 20 inches long and from 12 to 14 inches wide, slightly concave on top; it is supported by three feet, the two at the front being longer than the one at the other end. This arrangement causes the surface to incline downward from the *tortillera*, who kneels, while facing her work, at the higher end of the stone. The decorticated corn is ground on the *metate* by means of a long, round, spindle-shaped stone (*metalpile*) held in both hands by the operator, who rolls or rubs the corn into a fine paste; it is then beaten between the hands into thin cakes and baked on an earthen dish heated over live coals. The earthen jars for holding the corn while subjected to the action of lime-water, the shallow dish for holding the griddle-grease, the earthen pan resting on a group of stones over the fire, the fuel ready at hand, the covered pan of baked cakes, and the woman grinding behind the mill, are all represented in the Figure.

The women of the Pima Indians of Arizona gather great quantities of mesquite-beans, which grow wild in abundance, and which, when nearly ripe, are dried hard; in preparing them for food they are first pounded in a wooden mortar, and are then boiled until they become soft. These Indians convert their wheat into flour by grinding it by hand on their *metates*, which are large flat stones, on which the wheat is placed after having been slightly parched over the fire, and is then ground into coarse flour by rubbing and crushing it with another, smaller stone.

Mortars and Pestles.—In the year 1819 there was disclosed in the alluvium of the carse-land where the river Forth winds its circuitous course through ancient historic scenes rich in animal remains and prehistoric weapons a primitive quern, or mortar, fashioned from the section of an oak, such as is yet in use by some tribes of American Indians for pounding their grain.

The mortar (*mortarium*) used by the Romans was formed of a stone or other solid material hollowed into the shape of a shallow basin, in which ingredients were kneaded and mixed with a small pestle worked by one hand in a round-about direction. The *pilum* was a large and powerful instrument for braying materials in a deep mortar. It was held in both hands, and the action employed when using it was that of pounding by repeated blows.

The Roman *pistor* literally means "one who pounds corn in a mortar"—that is, a miller; because in very early times, before the invention of mills for grinding, the corn was brayed into flour with a very heavy pestle. Subsequently the same word signified "a baker," because bakers ground the flour with which they made their bread.

Pliny says that, in the estimation of some, bread made of broken grain is superior to that more finely ground in the better-constructed mills;

hence the inference that throughout the greater part of Italy grain for bread was pounded in a mortar with an iron-shod pestle. In course of time the mortar was ridged and the pestle notched, forming a machine which had a grating action on the grain.

Dr. Tschudi describes four of the Peruvian mortars, which were carved in porphyry, basalt, and granite. Two examples are given in Figure 12. One, a *llama*, 4 inches in length, from Húarmachaco, is cut in a close-grained block of stone; the other is of darkish-brown schist (Wilson).

Dampier (1689) relates that on the island of Mindanão the so-called "libby tree" yields a white pith, which the natives scrape out and beat lustily with a wooden pestle in a great mortar or trough, and which, after being formed into cakes and baked, furnishes a very good bread. Cuming says that among the Tahitians a pestle of stone provided with a crutch-like handle is used for pounding the bread-fruit on a wooden block. Niebuhr found in Arabia not only hand-mills, but also oblong, hollow grinding-stones, and spindle-shaped pestles thick in the middle and pointed at both ends. In the concavity of the stone the soaked corn was ground to meal with the pestle. In early times in England soldiers and officers while in camp prepared a peculiar bread called *militaris*. For this purpose they occasionally employed hand-mills, though the corn was generally pounded in a mortar; the meal was then made into cakes, which were baked on live embers.

Indian corn was the staple product of the aborigines of North America. The dry grain was prepared for boiling by crushing it into coarse particles with pestles in a rude wooden or stone mortar. This severe labor was performed by the women, who each day prepared the requisite supplies. The ancient stone pestles found in the fields formerly occupied by the Indian tribes throughout the Atlantic States afford abundant evidence of the practice of using these simple implements. For one person a single gill of meal mixed with water was sufficient for the day, as was the case with the *piola* of the Mexicans, which consisted of parched corn well ground and seasoned with sugar and spices.

The mode of pounding maize varied considerably. The women exercised their ingenuity in the use of the pestles and mortars, which were sometimes elaborately made. Figure 14 shows the perfection to which the hominy-block was carried. Its hard-wood pestle, 4 feet in length, was smoothly wrought and its ends were rounded, with reduced centre for easy handling; the hollowed-out log beside it is a receptacle for the saturated grain. On the head of the implement (*fig.* 8) found in Massachusetts is an ingeniously wrought symbol which is the name of the owner of one of these antique pestles. This symbol or totemic device is a deer, apparently the fawn. The substance employed is a species of graywacke.

The corn-cracker of the Pequea Indians found on the Potomac River much resembles that shown in Figure 7. The double-chambered ancient implement shown in Figure 10 was found by Schoolcraft near the site of

the present city of Buffalo. It is of the cornutiferous limestone of Western New York.

Figure 15 shows the mode of pounding maize by suspending the stone pestle from the limb of a tree, as practised by the Pennacooks of the Merrimac Valley, in New Hampshire. The pestle, commonly ornamented with the head of a man or of a quadruped, was neatly carved from graywacke or compact sandstone, the mortar being also of the same material.

Mortars—mostly made of hard sandstone—from 5 to 24 inches in diameter and from 2 to 12 inches in depth, of rude workmanship and without ornament, have been found in great numbers in graves in Santa Barbara, California. Specimens of the larger kind, found in graves at La Patera, are symmetrical in shape and have within and without a well-marked projecting rim, which served both to strengthen the utensil and to prevent the escape of the grain while being pounded. When broken, they were mended with asphaltum, which was also used to fasten ornaments to the rim. Many of the pestles found are simply smooth elongated boulders, while others show a shaping for a purpose, the collar on the smaller end suggesting a provision for suspension, as by the Pennacooks, above mentioned, or to facilitate handling.

In the latitude of 42° 25′ on the north-west coast of America pestles of different shapes are frequently found, but the absence of mortars suggests that in early times, as at present, the pestles were mostly used to crush acorns on flat stones, around which were placed low bottomless baskets, each about 1½ feet in diameter, into which were thrown the acorns to be crushed.

Hunter, in his *Manners and Customs of Indian Tribes*, informs us that in some Indian villages visited by him there were employed for pounding corn one or two large stone mortars, which were public property. These were placed in a central part of the village, and were used in rotation by the different families.

The Latimer Collection of Antiquities from Porto Rico, in the National Museum, at Washington, includes mealing instruments in great variety. Some of the pestles have a burnished, oily appearance on the lower end. One is rough and bell-shaped, with a rude human face on the top (*fig.* 13); others are cylindrical, conoidal, oblong, or flat. The lower stones are hemispherical and bowl-shaped, oblong, dish-shaped, or deeply concave; one, a very beautiful and unique specimen, is a boat-shaped mortar or dish, sharp at each end and deeply concave.

In Figure 11 is represented a mortar and pestle used by the Ainos of Yezo, one of the Japan islands, which is not well suited to rice-growing, but which produces wheat, and therefore requires mills to prepare the grain for food. This mill is figured in *Unbeaten Tracks in Japan*, by Isabella L. Bird, who visited this island in 1878.

"The door of every country-house in Cuba, be it dwelling or *bodega*, is ornamented by the unattractive but useful coffee-mortar, with its clumsy wooden pestle, and a sieve made of *pita caruja* hangs by its side, in which

the contents of the mortar are tossed in the wind and the light husks blown away, leaving the firm, hard berry" (McHatton-Ripley).

Thus far we have considered a variety of primitive appliances for grinding grain by hand alone, embracing the rude utensils for hammering it out on a rock with a cobble-stone and the various gradations of natural and artificial mortars and pestles, as also the implements employed in the weary hand-process of roller-mashing. The ancient corn-mill and the modern mealing-implement scarcely differ in their construction or operation, while the drudgery of grinding has always devolved upon women. We shall next consider the development of those methods whose employment has materially lessened labor, and which at the same time have produced far more satisfactory results.

2. WHEEL-MILLS.

Development of a Hollowed Stone into a Mill.—In the course of time the cavity of the stationary stone became deepened, and a handle was attached to the ball, whereby there resulted the mortar and pestle; so, again, when the upper stone was enlarged and provided with a central hole and a handle, by which the stone was rotated on a peg or pivot in the lower stone, there was produced the quern or hand-mill, which is the germ of the modern flour-mill.

Ancient Hand-mills.—Wheel-mills consist of a single pair of stones of similar form, with fitting surfaces, one of which (the upper stone or runner) is caused to revolve in near contact with the other (nether or bed-stone), the grain being ground between the two while passing in a direction from the centre to the circumference. By both ancient and modern writers the term "corn-mill" has been applied to a mortar-and-pestle mill as well as to a mill composed of a pair of stones, one of which is fixed while the other revolves. In connection with the earliest Scripture reference to the "mill" (Num. xi. 8) there is mention of the use of the "mortar," both of which implements were employed for reducing manna to powder. We have no description of the form of the mill in which the manna was "ground," but we may presume that revolving millstones were employed. At an earlier date the "king of Salem brought forth bread and wine" (Gen. xiv. 18), from which we may infer that mills for grinding grain and machines for expressing the juice of grapes were employed in the earliest times. This is the first Biblical reference to the use of machinery for the preparation of food.

Though there is a difference of opinion as to the size and weight of the stones, it is evident that the running stone must have been sufficient for crushing the grain; this weight, however, can be obtained in a stone of small as well as in one of large diameter, if the thickness be proportioned to the diameter—a well-known fact in milling-mechanics.

Considering its construction in detail, the mill of the ancient Hebrews may be regarded as a very simple machine. A hand-mill of twin-stones cannot exist in many forms nor be complex in its essential features, since

it is composed chiefly of a revolving part, called by the Hebrews a "chariot" and by the Arabs a "rider;" it is turned by the hand over a nether or stationary part, whose upper surface may be flat or convex, and this surface may also be even or grooved, but must always be hard and porous, for preserving the cutting-edges. In either case the central orifice of the upper stone may vary in shape, and yet fulfil its office equally well. If the hole be conical, it can be more easily cut, and will serve as a hopper to receive and hold the little charge of grain to be ground. The pivot upon which the rider turns may have been of stone, wood, or metal, rudely shaped or cunningly carved, fitting a guiding-bar or not, according to the ingenuity and skill of the millwright who built it; and the handle may also have been a mere wooden peg stuck loosely or fitting tightly in a hole in the stone, or it may have been a smooth, round handle of metal firmly fixed therein, probably covered with a loose leathern sleeve or shield of metal, to prevent abrasion of the hand—a refinement of mechanism easily born of necessity from painful experience, as the labor of turning it was manifestly severe, and necessarily required daily repetition, to meet the constantly recurring demands for bread.

In course of time, that the mill might be driven by cattle, shafts were added for turning the heavy pestle. At first the mills had no spouts for conducting the corn to the eye of the upper stone, and were without troughs for receiving the meal as the grinding progressed. Primarily, the human hand served the purpose of a hopper, and every woman employed at a mill was a miller. The hopper was a late invention, referred to, it is said, only in the Mishna, where, also, mention is made of a miller, indicating that grinding corn was recognized as a distinct occupation; but if millstones with central openings had been previously used, the hopper, as a separate invention, was thereby anticipated.

The Etruscans (500 B. C.) scored or furrowed the inside of their mortars, grooved the bottoms radially, gave to them a more cylindrical form, and roughened the lower end of the pestle. The latter was kept in the central position by an iron spike projecting from its lower end and entering a hole in the centre of the mortar, and the pestle was rotated on its vertical axis by means of a handle projecting laterally.

Eastern Hand-mills.—Modern writers familiar with the mills and methods now employed in the East for grinding grain are unanimous in their belief that the ancient hand-mill differed but little from the one in use at the present day. This consists of two circular stone discs (*pl.* 2, *fig.* 10) 15 inches in diameter, the lower one being about 2 inches and the upper one 2½ inches thick. In the centre of the lower stone is firmly fixed an iron pin ⅜ of an inch in diameter and 4 inches high. Through the centre of the upper stone there is an opening 3 inches in diameter, and across this, near the grinding-face of the stone, is tightly fitted a wooden bar ½ an inch thick and 1¼ inches wide, which is perforated at its centre, to fit over and to turn freely upon the pin in the lower stone. In a hole on the top surface of the upper stone, near its edge, is inserted a hard-wood

handle, by which the mill is turned. The grinding faces of these stones are flat, and their surfaces are neither grooved, notched, nor furrowed.

Though the ancient mill was sometimes turned by one woman, it was, because of the labor involved, more frequently worked by two women (*pl.* 3, *fig.* 1); these sat upon the bare ground, often in the dust, each with a hand pushing and pulling alternately the handle of the upper stone and together turning it around; at the same time one of the women with her free hand threw the grain into the central opening of the upper stone, which served as a hopper to direct the grain into the joint between the stones, where it entered as the upper stone turned and ground away the advancing grains.

To make comfortable the position of the grinders, who sit on the ground, and to enable them more easily to perform their labor, the mill, when in use, is placed upon a box or flat stone about 6 inches high. A cloth is invariably spread under the lower stone, to receive the meal as it issues from the outer edges of the stones.

Most of the hand-mills, as well as the larger mills which are turned by animals or water, in Palestine and Syria, are of basaltic rock taken from the great lava-bed in Bashan, where they are made, and whence they are transported to all parts of the country; the millstones are always of the hardest readily obtainable material. The diameter and thickness of the stones vary in different mills, but in the same mill the diameters of the upper and lower stones are always equal. As these mills must be carried about on the backs of animals, unnecessary weight must be avoided; the sizes, therefore, do not generally exceed those given above. The cost of a new mill of Bashan stone is from four to five dollars, but an inferior second-hand mill can be purchased for half this amount.

Some upper millstones are more shapely on the edge and on the face than the one shown in Figure 10 (*pl.* 2); for example, in Figure 1 (*pl.* 3) a thicker stone is cut away to about 2 inches around the outer edge, leaving a rim at the eye, forming a hopper; but multitudes are rudely formed, as the one represented in Figure 10 (*pl.* 2). In ancient ruins there have been found many under stones with convex grinding-surfaces, to fit which the upper stones are concave. The ancient mills were also more elaborately made in other respects than are modern mills, the art having degenerated with the people, who now require only a mill that will grind grain. The largest ancient millstone ($11\frac{1}{3}$ feet in diameter) of which we have knowledge lies on the Shittim plain, east of the Jordan, opposite Jericho, and has not been used for centuries; a wooden curb was originally fastened around the top, and the mill was used for grinding olives (perhaps grain also) on a large scale.

Anthony Francis Gori, in a *Memoria* published at Leghorn in 1752, makes mention of a red jasper on which is engraved the naked figure of a man who in his left hand holds a sheaf of corn and in his right a machine that is in all probability a hand-mill. Gori considers the figure a representation of the god Eunostus, who, as Suidas says, was the god of mills.

The machine, which stands on a table and is shaped like a chest, narrow at the top and wide at the bottom, is engraved on a small stone not more than ½ an inch across. In the bottom of the machine there is a perpendicular pipe, from which the meal appears to be issuing, and on the top is an aperture, perhaps occupied by a basket, from which the corn falls into the mill. From one side there projects a broken shank, which probably represents the *molile* or handle. Though this small figure conveys but a vague idea of its design, we may conclude that the roller, whether of wood or iron, smooth or notched, lay horizontally, thus indicating a construction more ingenious than that of previous inventions. The axis of the handle may have had within the body of the mill a crown-wheel turning upon a spindle, to the lower end of whose perpendicular axis the roller was fixed. On the side opposite the handle there arise two shafts, which may represent a besom and a shovel, though more probably they are parts of the mill itself.

Roman Hand-mills: Trapetum.—A very early example of the edge-stone mill or "chaser" (*pl.* 2, *fig.* 1) is the Roman *trapetum* or olive-mill, employed for bruising and separating from the stone the fleshy part of the olive before submitting it to the action of the press. The Figure gives both elevation and section, with the different members properly adjusted. Rich mentions the *mola luxea*, a small wooden hand-mill for grinding pepper and similar spices, wheat, beans, or lupines.

Pompeian Mill.—In the bakers' shops at Pompeii there have been found several similar mills, consisting of two stones cut in the peculiar shape exhibited in Figure 4, which represents the mill with both stones adjusted for use. The lower millstone (*meta*) is a cylindrical monolith about 5 feet in diameter at its base and 2 feet in height, tapering cone-shape to its apex, to which an iron pivot is fastened. The upper stone (*catillus*) is shaped like an hour-glass, whose upper half is the hopper, the lower half fitting the conical projection of the lower stone. A socket, made for the purpose, in the centre of the waist, or the narrowed part between the two hollow cones, receives the iron pivot, which serves the double purpose of keeping the upper stone in position and of diminishing or equalizing the friction. The corn descends from the hopper through four holes about the pivot to the solid cone, where it is ground between the upper surface of the latter and the inner surface of the *catillus*, which is turned by means of radial bars (inserted in the sockets of an iron hoop) worked by slaves. A channel is cut around the cylindrical base, to facilitate the collection of the flour which falls from between the millstones.

Querns, or Hand-mills.—The quern (*figs.* 2, 3) now in the Edinburgh Museum of Antiquities was brought from North Yell by Arthur Mitchell, from whose *The Past in the Present* we take the following description: The quern usually stands in a wooden tray, one end of which is built into the wall, the other end being supported on two legs. The lower surface of the nether stone receives little or no shaping, the level being obtained by a clay bedding; the upper stone is always the better finished. The

central hole of the under stone is tightly filled with a piece of wood, but through it there is an aperture just large enough to permit the wooden spindle to pass. The lower end of the spindle rests on a narrow board, one end of which lies loosely in a recess in the wall, and to its other end is attached a cord, which is passed double through a hole in the front of the tray, and then over a wooden button. By turning this button the two plies of cord can be shortened or lengthened, and in this way the board on which the lower end of the spindle rests is raised or lowered; from which it is clear that the runner stone will also be raised or lowered. It is this adjustment that permits of grinding coarse or fine; the actual method of obtaining this result is, with slight modification, the same as that in use in more modern mills. The quern is fed through a central hole of the upper stone, across which, on the under surface of the stone, is a wooden socket (*rynd*), which receives the upper end of the spindle. The handle for turning it is of wood, fixed in the upper stone, near its margin. Occasionally one end of a long handle lies loosely in a cup or hole in the stone, while the other end passes freely through a hole in a rafter of the roof of the cottage. In this way two persons can easily engage in turning it. The meal falls from all sides of the quern upon the tray and is removed from one of the corners of the tray, where the ledge is intentionally omitted.

Pennant, in his *Tour of Scotland*, says querns or hand-mills were in use in the Hebrides in 1772, and he gives a representation of a quern in operation. The handle for turning the quern was formed of a long stick of wood, one end of which was fastened to the branch of a tree and the other end inserted in a hole of the runner stone. Ornamented querns of various forms have been found in many parts of the British Isles, where in some districts they have been in use until very recent times. The stones of some have a diameter of from 3 to 3½ feet.

The wandering Arabs grind their corn in portable hand-mills which are simply two circular flat stones, one of which turns loosely on a wooden pivot fixed in the other, and is moved quickly by a wooden handle. The grain is poured through a hole in the upper stone, and the flour is collected on a cloth spread under the lower. These mills are always worked by the women. Figure 8 (*pl.* 2) represents a very simple hand-mill whose operating mechanism consists of a face-wheel which engages the trundle or lantern of the spindle, to the lower end of which is fastened the revolving or upper stone. The millstones are enclosed by a case.

Indigo-mill.—A hand-mill on the principle of the mortar and pestle is shown in Figure 6; this mill is used for grinding indigo. The muller or pestle is pear-shaped, with slotted base; its upper end is attached to an iron double-crank axle, to which, at its upper extremity, is added a weight adapted to the pressure required upon the muller. The indigo or other dry substance to be ground is thrown into the mortar, above the muller; on turning the handle on the axis the indigo in lumps falls into the groove cut through the muller, and is thence drawn under the action of the

muller and propelled to its outer edge, within the mortar, whence the coarser particles again fall into the groove of the muller, and are further ground under it.

Evolution of the Mortar and Pestle.—The usual construction of a mortar does not embody the self-discharging principle, but under the stimulus of necessity the whole process became reversed: the pestle was made the stationary part, and over this the mortar was carefully fitted; for the admission of the grain a central eye was cut through the mortar, to which a handle was finally adapted. Much was gained by this arrangement. The grain, falling on the summit of the nether stone, ran into the joint between the two, where it was ground as the upper stone turned, the latter carrying with it the crushed grain, which by abrasion and gravity worked its way through and escaped, fully triturated, at the periphery of the stones. Ancient mills were made in this way; the Pompeian mill shown in Figure 4 (*pl.* 2) is an implement of like character.

As an evidence of the value of this principle, and as an illustration of the numerous instances of reinvention, we quote the following specifications of a mill patented in the United States in 1829: "A pair of stones is put in operation somewhat similar to those of a grist-mill, except that the lower stone is the runner, instead of the upper one, and the face of the upper stone is concave, and the lower one convex, that they may clear themselves the more readily, and thereby facilitate the grinding. The acclivity of the face of the nether stone forms an angle with the horizon of about thirty degrees, and that of the upper a greater angle, to receive the articles to be ground, while the stones may run quite close at their peripheries. The upper stone has a large eye and is surmounted by a hopper."

The Foot- or Tread-mill, which is operated by the impulsive force of the feet of men, is shown in Figure 9. It consists of an inclined wheel, to whose face cross-strips of wood are fastened radially at proper distances apart, to prevent foot-slipping. The under side of the wheel is provided with teeth, which engage with the cogs of a trundle, turning the horizontal shaft and the wheel at its extremity, which, in turn, engages with the trundle of the vertical shaft, causing it to revolve, together with the millstone on the upper end of the shaft. The hopper conducts to the eye of the millstone the grain, which, when ground, passes out from the stones by the spout, as seen in the illustration. Rich gives a picture (*fig.* 5) from a marble in the Vatican of the *mola asinaria*, or *machinaria*, a mill worked by cattle instead of by men.

Camp-mills.—Portable mills, denominated "camp-mills," have sometimes been taken with armies as a part of their necessary equipment. Some of these mills are of stone, while others are constructed with a notched cone, which revolves like that of a coffee-mill. They are occasionally so constructed that they can be propelled by the wheels of the carriages on which they are placed, but they are more frequently driven by horses or by men. The portable army-mill (*fig.* 7), a French invention, stands on

a tripod and is driven by two men at the crank-handles. As the material is ground it falls into the suspended sack. Four of these machines, packed in two boxes, make up a load for a mule on the march.

Water-mills.—All mills which receive their motion from the impulse of water are designated as water-mills. Very little is known concerning the application of water-power for the purpose of grinding grain in ancient times. The following epigram of Antipater, a contemporary of Cicero, implies that water-mills in his day were not common in Europe: "Cease your work, ye maids, ye who labored in the mill; sleep now, and let the birds sing to the ruddy morning, for Ceres has commanded the water-nymphs to perform your task; these, obedient to her call, throw themselves on the wheel, force round the axle-tree, and by these means the heavy mill."

Vitruvius, who was a prolific writer on a variety of subjects, informs us that water-mills were in use in the time of Augustus, and that for raising water there were employed wheels which were driven by being trodden upon by men. Palladius, who lived in the fourth century of our era, advises the building of mills on possessions that have running water, so that corn may be ground without men or cattle. More than three centuries after Augustus there were three hundred cattle-mills in Rome, whose use, it seems, as well as that of hand-mills, was regulated by law. Public water-mills were not employed, however, until near the close of the fourth century, and during the following century they became so common that strict laws were required to regulate the use of the water drawn from the canals which supplied the city.

When Vitiges besieged Rome, A. D. 537, he cut off the supply of water from the aqueducts which fed the canals. Deprived of power from this source, Belisarius placed boats on the Tiber and on them erected mills. These consisted of two boats moored 2 feet apart, and, suspended on its axis between them, a water-wheel which was driven by the force of the current and put in motion the stones for grinding the corn. This appears to have been the origin of "floating mills."

Roman Water-mill.—A mill (*pl.* 3, *fig.* 2) in operation at the beginning of the Christian era is described by Vitruvius as follows. Around the fronts of the wheels are affixed *pinnæ* (*A*), which, when impelled by the current of the river, force the wheel to revolve. By these means the *hydromylæ* (water-mills) are turned. On the water-wheel axis is a toothed tympanum (*B*) turning with the water-wheel. Adjoining this tympanum a larger one (*D*), also toothed, is placed horizontally; in this is contained an axis (*E*) having at its upper end an iron dovetail (*F*), which is inserted in the millstone (*G*); thus the teeth of the tympanum (*B*), that is included on the axis impelling the teeth of the horizontal tympanum (*D*), cause the rotation of the millstone, to which the suspended hopper (*H*) furnishes the grain, and by the same rotation the meal is ejected. The expression *aquimolum molendini*, found in one of the charters, perhaps indicates that the mill referred to was a grinding-mill proper, and that as

early as the eleventh century water-mills were used not only for grinding corn, but also for other purposes, although hand- and cattle- mills were employed for a long time after the erection of water-mills.

The mills found on Mount Lebanon and on Mount Carmel at the beginning of the eighteenth century nearly resembled those found in many parts of Italy; they were exceedingly simple in construction. To the same axis were fastened the millstone and the motor-wheel, the latter consisting of eight boards shaped like shovels and placed across the axis. The water, falling upon these boards, turned them round and put in motion the millstone, over which the corn was poured.

The Algerian Water-mill shown in Figure 3 (*pl.* 3) is an ingenious contrivance. Beneath a timber platform supporting the millstones is a funnel-shaped boarded chamber for the wheel, which is driven by water from a pipe conduit. The runner-stone, which is of less diameter than the bed-stone, is rotated by the water-wheel spindle. The flour is discharged around the bed-stone and falls on a clay floor, from which it is gathered into sacks.

Persian Water-mills.—On the frontier between the Persian province of Khorassan and the Akhal-Tekin oasis there are some very curiously constructed grist-mills. Below an elevated lake a series of dykes is so built as to cause the water to fall over long steps, and at each place of descent is fixed a grist-mill with its turbine, through which the water passes. The mill-house (*fig.* 5) is a sort of mud hut lighted only by feeble lamps. The turbine turns the horizontally arranged stones, over which hangs a bag of pyramidal form, serving as a hopper; from an opening in the lower stone the flour runs out upon the floor, whence it is taken up by a scoop.

Water-mills of the British Islands.—Dr. Johnson, in his *Journey to the Western Islands of Scotland*, says, "There are water-mills in Sky and Raasa, but where they are too far distant the housewives grind their oats with a quern or hand-mill, which consists of two stones about 1½ feet in diameter. The lower is a little convex, to which the concavity of the upper must be fitted. In the middle of the upper stone is a round hole, and on one side is a long handle. The grinder sheds the corn gradually into the hole with one hand, and works the stone around by the handle with the other. The corn slides down the convexity of the lower stone, and by the motion of the upper is ground in its passage."

Water-mills were formerly common in Great Britain and Ireland, and continued in use well into the present century. Sir Walter Scott, in his voyage to the Shetland Islands in 1814, visited a mill which he described as follows: "In our return pass the upper end of the little lake of Cleik-him-in, which is divided by a rude causeway from another small loch, communicating with it, however, by a sluice, for the purpose of driving a mill. But such a mill! The wheel is horizontal, with the cogs turned diagonally to the water; the beam stands upright, and is inserted in a stone quern of the old-fashioned construction. This simple machine is enclosed in a hovel about the size of a pig-stye, and there is the

mill. There are about five hundred such mills in Shetland, each incapable of grinding more than a sack at a time."

Norse Water-mill.—On Plate 3 (*fig.* 4) is represented a perspective of one of the Shetland water-mills known as "Norse mills." Suspended from the roof by straw ropes is the hopper, which receives the necessary vibratory motion for feeding the stones by means of a stone, fastened to a cord, lying loosely on the surface of the runner millstone, whose roughness as it goes round makes the cord irregularly tight and slack as the result of its varying drag. The millstones are rarely more than 3 feet in diameter; the meal is delivered on the floor around the stones within a space laid off by a ledge of wood. The Norse mill is usually the property of a township or of several contiguous townships. All the families of the community have the use of the mill, and when meal is required carry their corn to the mill and are their own millers.

Mexican Water-mill.—What may now be called the "old-time" machinery of milling in Sonora, Mexico, consisted of single-run millstones, usually manufactured from the hard rock of the country; they were driven by the mountain-streams. The mill-house was usually a small *adobe* building of a single room, in which the stones were placed without a curb. The Mexican miller was ingenious, but not inventive. The wheat, with its admixture of stones, dirt, etc., was placed in the hopper, over the eye of the stone; the mill was then started, and left by the miller to its own devices. The result was a perfect cyclone of "chess" until the feed was exhausted, when the miller returned and swept up the flour.

Tidal Mills.—As their name indicates, tidal mills are those which employ for power the flowing and ebbing tides. At Venice and in some other places there were constructed mills adapted to take advantage of the tide by a change every six hours of the position of the wheels. Such mills are said to have been in operation at the middle of the twelfth century.

Spanish Tidal Mills.—The tidal flour-mills of Andalusia are little known beyond that locality; they are interesting not only on account of their primitive simplicity, but also because they present the earliest form of the turbine-wheel, which has come down in its present mode of construction from Moorish times, if not from an earlier date. These mills, which are numerous on the salt marshes bordering the lower portions of the Andalusian rivers within the tidal range, are built across the creeks, whose natural capacity is so increased by excavations as to retain at spring-tides from half a million to a million cubic feet of tidal water. The head, which rarely exceeds 7 feet, will, with a run of three or four stones, work a mill about six hours, though the number of stones that can be worked simultaneously is regulated by the height of the tide; the mills are all stopped at neap-tides.

The mill-houses are of one story, with upper structure built as light as possible; at one side there is an opening 7 or 8 feet wide, through which the tide-water flows, and which is covered by a strong wooden shutter opening upward as the water enters and closing when the cur-

rent of the water begins to return to the sea. The foundations of these mills are rudely placed on broad flat stones, which are widely scarped and heavily buttressed. The chambers enclosing the wheels are built in culverts formed of brick underneath the mill, and to these chambers the water is admitted through square holes, which are covered and uncovered by means of a rough plank. Between the wheel and the brick chamber there is considerable space, through which much water escapes unutilized.

The wheel, which is made of the hardest wood obtainable, is horizontal, and partakes more of the nature of a dash-wheel than of that of a turbine, because it is actuated more by the current of the water than by its pressure. Its diameter is about 5½ feet, and it contains twenty-seven blades, formed of quartered logs roughly hewn and keyed radially into a vertical shaft like the spokes of a cart-wheel; they are about 4½ inches wide by 3 inches deep at the periphery, and are curved and rounded at the back and hollowed out on the upper side. To the extent of 8 inches above and below the wheel the shaft has a diameter of about 10 inches, and from this diameter it tapers under the stone to 4½ inches. It communicates motion directly to the upper stone by an iron gudgeon 1¾ inches square, which is secured in the axis of the shaft by iron rings tightened with wedges; it passes through the centre of the lower stone, having a bearing composed of brass or a wooden bush; its top end extends and fits into a cross-bar sunk into the face of the upper stone. The lower end of the shaft is pivoted on an iron spike resting in a plate nailed to the bridge-beam, one end of which rests in a hole in the wall, and to the other end of which a wooden bar is secured, which passes through the floor to a place convenient for raising and lowering the stone.

The millstones, taken from quarries near Jerez, are about 4 feet in diameter, and when new are 13 inches thick. For convenience, they are turned over for dressing. The corn is placed in an inverted pyramidal box holding about 1½ bushels, and escapes through its apex, by means of a small wooden shoot, to the central opening of the upper stone. In its passage thence it is shaken by a stick tied to the shoot, one end resting upon the rough upper surface of the stone, whose revolutions keep it constantly in motion. These mills are easily managed, and each will grind about 1½ bushels per hour.

Barker's Mill (*pl.* 3, *fig.* 6) is an apparatus which is driven by the reactive force of water. A vertical axis (*C*, *D*) moving on a pivot (*D*) carries the upper millstone (*m*) after passing through a packed central opening in the fixed millstone (*C*). Around and upon this axis is secured a vertical tube (*T*, *T*) communicating with a horizontal tube, at whose extremities, upon its opposite sides (*A*, *B*), are two apertures. Water from the fore-bay (*M*, *N*) enters the tube (*T*, *T*), and its efflux through the apertures of the tube acts by counter-pressure upon the interior sides of the arms (*A*, *B*), opposite to the apertures; consequently, the whole machine is put in motion. The bridge-tree (*a*, *b*) is elevated or depressed by turning, at the end of the lever (*a*, *b*), the nut (*c*), by which the distance apart of the stones is

regulated to the desired fineness of the grinding. The grain is deposited in the hopper (*H*), from whose lower orifice it drops into the eye of the upper millstone.

Wind-mills.—The date of the invention of the wind-mill is not definitely known, although authorities generally concur in the belief that it is comparatively recent. Mabillon mentions a diploma of the year 1105 in which a convent in France is allowed to erect water- and wind-mills (*molendina ad ventum*). Many were built in that century. In the year 1332 a proposition was made to the Venetians to build a wind-mill. In 1393 the city of Spires caused a wind-mill to be erected, and sent to the Netherlands for a person acquainted with the method of grinding by it. A wind-mill was also constructed in 1442 at Frankfort. Wind-mills were used in the East only in places where no streams of water existed.

In the Middle Ages the natural right of man to employ water and wind as he pleased was frequently questioned. It is related that at the end of the fourteenth century the monks of the monastery of St. Augustine, at Windsheim, in the province of Overwissel, desired to erect a wind-mill, but were forbidden by a neighboring lord, who claimed that the wind in that district belonged to him. The bishop of Utrecht, however, to whom appeal was made, declared that no one but himself and the church at Utrecht had control of the wind in his diocese, and by letters patent dated 1391 he granted full power to the monks to build for themselves and their successors a good wind-mill wherever they chose.

The Old Wind-mill at Nantucket (*pl.* 3, *fig.* 7), built in 1746, was made chiefly of oak timber which grew on the island. With half-spread of sail it will grind fifty bushels of corn per day; doubling the width of sail over the arms will increase the grinding capacity proportionally. The mill-house is fixed, while the wind-wheel, together with its shaft and cog-wheel, that engages in the trundle on the millstone spindle and the roof that covers them, is turned around to face the wind; this is accomplished by means of the tail-beam with a wagon-wheel on its end, as seen in the illustration. This wheel is worked around by hand, and is anchored in the required place. This mill was used for semaphore signalling in 1779 to warn American vessels coming in of the whereabouts of the English. Prior to its erection three other wind-mills had been built on the island, the first in 1723.

The Post-mill (*fig.* 8) is constructed by setting perpendicularly into the earth a strong post, which is held securely upright by several oblique braces. The upper part of the post is rounded and passes through a circular collar in the flooring of the lower chamber, and into a socket fixed in one of the strong cross-beams of the flooring of the upper chamber, which must sustain the whole weight of the mill-house, and by means of a pivot or gudgeon on that part of the post which enters the socket the whole machine can revolve horizontally, to face the wind. The interior arrangement of a post-mill is shown in the Figure. The upper chamber contains the operating mechanism, which consists of a horizontal shaft or

axis, on whose end is a cog-wheel engaging the trundle on the spindle attached to the upper millstone. The lower stone is somewhat larger than the upper stone. The corn is fed from the hopper through a spout, which is shaken by the revolutions of the square end of the spindle. The flour passes from the stones through the tunnel at one side, and thence to the chest, in the lower chamber. By a suitable mechanism the stones can be adjusted the proper distances apart and the mill can be stopped and started at will. The bags of corn are drawn to the top of the mill by a rope wound about the axis of the shaft.

Reinventions.—Improvements in the construction of grain-mills were gradually effected from time to time during the course of the Middle Ages, and in common with the progress of culture in general. It was not, however, until an impetus was given to invention by the enactment of the first British patent laws, early in the seventeenth century, that the improvements made by one or other individual mechanic became known beyond the precinct of the inventor's mill-house or the narrow limits of his native locality. It was but natural that under the incentive offered by the crown-patents many an old idea should be resuscitated and made the subject of patent-right.

In 1637 there was granted to George Mandy a patent for an invention relating to the "makinge, tryminge, selling, and putting out to hire of a new form of mills for the grindinge of corn," etc. In 1682 letters-patent were issued beginning, "Whereas wee have beene informed by our trusty and well-beloved John Joachim Becher, Doctor of Lawes, that hee, with greate charge and study, hath found out and discovered A New Way for the makeing and erecting of floating mills vpon the River Thames and all other Navigable Rivers, for the Grinding of all sorts of Graine," etc. In 1786 a patent was granted to Walter Taylor for "a machine in which the grinding surfaces are made of cast iron in form similar to the surface of the stones used by millers, such cast-iron grinding surfaces having grooves or furrows to admit of the flour passing. Steel cutters also may be fixed in the grooves." In 1827, Robert Vazie secured a patent for a mill which is described as follows: "The conical corn-mill operates, by means of two inverted concentric cones, by means of steel or other metal, one rotating on a vertical axis within the other, the external surface of the inner cone and the internal surface of the outer being grooved or channelled spirally in opposite directions to form the grinding surfaces, to and between which the grain is fed from a hopper above, and when ground falls from the open end or apex of the outer cone into a receptacle beneath."

3. MODERN POWER-MILLS.

A. MILLSTONE-MILLS.

The one-stone mill, driven by water or wind, proved a great advance over the Mosaic mealing-mortars and mills which had been used for centuries. The time had not come for developing and employing the full mill-power

of running streams or forceful winds, or the wonderful energy of steam. The mill-builders of the past appear to have had no conception of the superior advantages of large water- and wind-wheels or of the systematic distribution of their power, but confined themselves to the primitive idea of driving one millstone by one wheel, and of bolting with one reel. Most of the mills in the East, in Europe, and in America were arranged on this plan up to about the middle of the last century, and some such are still in use. During the days of Smeaton, the eminent English millwright, mills began to be planned and constructed on what are now denominated "engineering methods," which soon led the way to the perfection of milling-plants now everywhere employed.

Elementary Principles of Mill-construction.—From the time of the earliest revolving millstone to the present, certain essential elementary principles and mechanical devices of construction have been embodied in the building of the mill—namely, the fixed lower stone, the revolving upper stone, and the horizontal and nearly parallel grinding surfaces of the stones. The runner stone is fixed to, or hung loosely on, the top of a vertical spindle passing through the centre of the lower stone, and the foot of the spindle is carried on a bearing so devised that it may be raised or lowered while in motion, for the purpose of regulating the space between the grinding surfaces of the two stones. Moreover, means are provided for regulating the feed; a speed of rotation is established sufficient to throw out the ground material; and the millstones are enclosed in a case, from which the meal is delivered by a pipe. For separating the finer meal from the coarser particles and the bran, a hand-sieve was until quite recently the only device employed.

Bolting.—It is highly probable that in the early history of milling the process of bolting was not resorted to, and that unbolted flour was used for baking. When it seemed desirable to secure the finer products of the grain by excluding the bran, a sieve moved by hand was employed for the purpose. A sieve in the form of an extended bag, to receive the meal from the stones and to be turned and shaken by the machinery, was first adopted in the beginning of the sixteenth century. In 1502 machinery for bolting in mills was first introduced and employed at Zwickau by Nicholas Boller.

Dress of Millstones.—Great ingenuity has been displayed upon the draft and dress of millstones (*pl.* 4, *figs.* 8–13), about which the opinions and practice of millers differ widely. Dress is the system whereby the face or grinding surface of the stone is prepared by lands and furrows. The grooves which expedite the grinding action are termed "furrows," and the level surfaces between the latter are the "lands." Grinding is partly on the principle of shearing; and to effect this object the "furrows" on the faces of the millstones are cut obliquely to the radius. Refinements of mechanism, however, are apt to lead too far in one direction; for example, Professor Kick states that, in 1873, Franz Schmid of Lanzendorf experimented by reversing the direction of the runner stone, but did not observe any particular difference in the quantity or quality of the material ground.

The Mill-pick (*pl.* 4, *fig.* 7) is a tool for dressing the face of millstones after they have become smooth by use; the dressing gives to the burrs a furrowed surface adapted to grinding. The illustration shows one of the many forms of picks devised for the purpose; it is a lozenge-shaped bar of steel with a chisel-edge at each end, and is made exceedingly hard and tough by skilful forging and tempering. The handle, which is usually of hard wood, has a split head and is bound with metal.

Low Grinding.—Up to within ten years the system of making flour was exclusively by what is now known as "low grinding" or "low milling," which is the ordinary system of making flour by one grinding and of separating the meal by a single bolting. In this operation, however, the wheat-germs and much of the bran are reduced too fine for complete separation, resulting in an impure flour which, though it will not keep, is preferred by many for domestic use.

High Grinding.—The more modern system of high grinding avoids as far as possible the production of flour during the first passage of the grain through the millstones. The principle involved in this process is that of a system of successively graduated crackings of the wheat, with alternate separations of the bran and flour as rapidly as they are produced.

Half-high Milling is the system in which the grain receives more cracking than in low milling and more pressure than in high milling. Each of the above methods is best suited to certain kinds of grain—low milling for soft wheats, and high milling for hard wheats.

Cylinder- or Roller-milling is the improved modern method of making flour. This is the system of shearing the wheat-berries by grooved rolls and of mashing and grinding the fragments by smooth rolls, all of which have differential face velocities.

Disintegration is a system in which neither stones nor rolls are used, the wheat-grains being violently thrown against one another and struck by a hard body moving with a high velocity (p. 45).

The Decortication of Grain as a preliminary to grinding has been practised from the earliest times. The Romans pounded and rasped the grain with pieces of brick, and also with sand, in mortars. In England pearl-barley was prepared by submitting the grains to a grating action, but without crushing them, in a mill having a stone like a grindstone, roughened on its circumference, revolving in a grater-like metallic casing in which the serrated edges of the metal pointed inward and upward. In Germany decortication was done between millstones set close enough to rasp off the bran, but not to mash the kernel. In Mexico the practice is first to soften by immersion in lye or lime-water, and then to remove the hulls of the shelled maize by hand-roller mashing. The hulls are also removed by a thrashing and grating action in the hominy-mill. A Prussian practice is to decorticate by centrifugal action, whirling the grain at a high velocity against a perforated grater, through whose meshes the dust and bran are driven.

Structure of the Grain.—Fully to understand the action of the decorticating-mill, a brief description of the nature and structure of the grain will be necessary. A grain of wheat is composed of the following membranes or coats and enclosed parts, which are clearly shown in the magnified sections on Plate 4 (*figs.* 1, 2). Naming them in order, beginning with the external skin (*fig.* 2), we have (1) the *epidermis*, (2) the *epicarpus*, and (3) the *endocarpus*, these three together forming the outer skin of the grain; (4) the *testa membrane;* (5) the *embryo membrane*, containing in its cells the substance to which the name "cerealine" has been given by its discoverer, the French chemist Mégé Mouriès; and (6) the *embryo* or germ. These six distinct parts constitute what is commonly called the "bran." Within these, and making up the entire central body of the grain, are (7) the flour-cells, to which the name of *perispermum* has been given. The three outer coats and the outer of the two membranes are composed principally of ligneous tissue, and constitute from three to five per cent. of the entire volume of the grain. The presence of cerealine in flour impairs the quality of the bread; the importance, therefore, of eliminating it in the milling process is apparent. Practically, flour which contains no cerealine is white, of fine texture and of palatable flavor, and will retain these qualities unimpaired for any length of time. The difficulty of entirely removing these coats from an unbroken berry of wheat by any machine acting upon its exterior may be clearly seen by reference to Figure 1, which represents the average normal size of the berry, also a section and cross-section of the same, magnified eighteen diameters, exhibiting the relative thicknesses of the outer coats, the flour-cells massed within, and particularly the peculiarly looped, infolded outline of the longitudinal groove running the full length of one side of the berry. It will be seen that a mechanical scraper may readily remove the outer coats from the rounded parts of the berry, but could not be so contrived as to penetrate the interior of the fold for removing every part of these coatings.

Decorticating-mill.—The hulling- or decorticating-machine shown in our illustrations (*figs.* 3, 4) consists of a cylindrical casing in which is a series of cast-iron discs fixed on a vertical spindle, which in running makes about three hundred and fifty revolutions per minute. Radially, and at right angles to their planes, the peripheries of these discs are set with thin steel blades from 12 to 16 per inch, which are separated by pasteboard interpacking of a less width and length, so that the edges of the blades project. The casing has open wire-work (*D, D*; *fig.* 4) on its two opposite sides, and the two intervening portions are lined with steel blades (*C, C*) similar to those on the discs, with a space of from 3/8 to 1/2 an inch between the ends of the blades of the discs and those of the casing. Between each of the revolving discs, and close to their circle of blades, is a fixed annular disc (*E*) furnished on its opposite sides with a similar arrangement of blades, thus dividing the machine into a series of horizontal compartments. At intervals in the fixed annular discs holes are made, which can be closed to any required extent by slides (*I, I*).

The grain, which is fed through a pipe (*G*; *pl.* 4, *fig.* 3) in the cover of the casing, passes down between the edges of the blades (*B*) on the first revolving disc and the fixed blades (*C*, *E*) on the casing, and thence down through the successive compartments to the bottom of the machine. A portion of the epidermis of the grain is removed by the action of each revolving disc, and the particles thus cut off, aided by a current of air, escape through the wire-work portions of the casing. The regulating-slides (*I*, *I*; *fig.* 4) of the annular discs afford the means of retaining the grain a longer or shorter time under the action of the blades in each compartment, and india-rubber brushes are inserted at *H*, *H*, for pressing the grain close to the revolving discs. The cleaned grain is delivered into the spouts (*J*, *J*; *fig.* 3) at the bottom of the machine. About seven per cent. of the whole grain is removed by this process. The portion removed is a dark, soft, and greasy substance whose presence is deleterious to the flour, but it has a commercial value, as food for cattle, equal to that of bran. The machine while in motion renews its cutting-edges: as the sharpness of the front cutting-edges of the blades is worn off a new edge is set up on the opposite side of the blades; so that it is only necessary to reverse the motion of the discs to maintain a constant and efficient action of the machine.

Oliver Evans's Mill.—Toward the close of the last and early in the present century, Oliver Evans invented and put in operation many mechanical devices which are entitled to be called "scientific." He gave the first impetus to the art of milling in America, and his patented improvements in milling-mechanics were finally combined into one complete system. His inventions for converting grain into flour embraced the elevator, the conveyer, the hopper-boy, the drill, and the descender, "which five machines" —quoting from his *Young Millwright*—"are variously applied in different mills, according to their construction, so as to perform every necessary movement of the grain and meal from one part of the mill to another or from one machine to another, through all the various operations, from the time the grain is emptied from the wagoner's bag or from the measure on board the ship until it is completely manufactured into superfine flour and other different qualities, and completely separated ready for packing into barrels for sale or exportation; all of which is performed by the force of water, without the aid of manual labor except to set the different machines in motion."

Evans's system of milling is illustrated in Figure 14, which exhibits the operation of his labor-saving machines. The following explanation of the Figure is condensed from his description: The grain from the wagon is delivered into a spout (1), which directs it to the scale (2). When weighed, the grain is drawn into the garner (3), at the bottom of which is a gate, that admits it to the elevator (4, 5), which raises and delivers it into the great store-garner (6), whence it descends through suitable connecting passages into the garner (7), over the mill-stones (8), where the grain is rubbed before grinding. As rapidly as the process of rubbing is completed the grain again runs (as indicated by the dotted

lines) into garner 3; in its passage thence it goes through an air-current blowing into an air-tight chamber (9), which contains a spout (*a*), extending through the floor for the escape of the air, which carries out with it (at *a*) most of the dust. The grain then again flows into the elevator (at 4) and is raised to 5, whereupon, the crane-spout being turned, the grain is deposited in the screen-hoppers (10, 11). From these hoppers it runs into the roller-screen (12) and descends (14) through a current of air generated by the fan (13) into the conveyer (15, 16), which conveys it to all the garners (7, 17, 18) that supply the millstones (8, 19, 20). The meal falls from the stones to the conveyer (21, 22), which carries it to the flour-elevator (23) and raises it to 24, whence it gently runs down the spout to the hopper-boy (25), which spreads and cools the flour and gathers it into the bolting-hoppers. As it passes through the first reel (26) the superfine flour falls into the packing-chest (28); the tailings, which require rebolting as they come from the first and second reels (26, 27), are guided by a spout (dotted lines 31, 22) into the conveyer (22, 23), to be hoisted again for further treatment. The middlings are conveyed into the eye of either pair of millstones by the conveyer (31, 32) and reground with the wheat. The light grains, screenings, etc., blown out by the fan (13) fall into the screenings-garner (32); the chaff, being driven farther on, settles in the chaff-room (33), while the greater part of the dust is carried out by the air through an aperture in the wall. To the left, in the Figure, is seen the system of elevating grain from a water-transport. It is raised to the top story of the mill, whence its course is essentially the same as that above described.

Fairbairn's Mill.—The stones of the Fairbairn mill (*pl.* 4, *fig.* 15) are formed each of several blocks of French burr, a very hard, siliceous yet porous mineral. These blocks are fitted together, cemented with gypsum, and bound with iron bands. They are 4 feet in diameter by about 1 foot thick. The working-face of the stones is dressed flat and is grooved, but the face of the upper stone is slightly concave for a small distance from the central aperture, to admit the grain between the stones, which are enclosed in a cylindrical case (*C*) supported by a bell-shaped cone (*B*) upon a strong oblong rectangular box (*A*) secured to a foundation by bolts. This box is provided with an adjustable bearing (*G*), for carrying the main driving-shaft (*F*), which by means of the mortised bevel-gears (*H*, *I*) turns the upper stone. A pivot-bearing (*k*) of bronze, supporting the mill-spindle (*J*) and permitting it to turn freely therein, is carried in a case (*b*) fitted to the upper shelf of the box. By means of a screw (*N*) outside the box, connected with a lever (*N*) carrying a saddle (*n*) on its middle, the spindle is raised or lowered at pleasure for different finenesses of grinding. The upper end of the spindle turns freely in a tight central adjustable bush (*L*) fixed in the under stone.

The central eye of the upper stone is supplied with a rynd (*K*), into which the ends of the cross-pin (*c*) project. This almost universal method of connection of spindle with stone balances the stone freely upon the end

of the spindle and permits an unconstrained action of the grinding surfaces upon the grain.

Combined with the rynd, on its top, is a cup-like cavity with central cone, which, in connection with the telescope tube (*O*), surrounds the funnel up to the hopper (*E*), and is made adjustable, as to its vertical position, by the lever *P*. The chain and hand-wheel screw (*q*) enable the miller at any time to regulate the supply of grain to the mill from the hopper. This ingenious device permits an even and regulated flow of the grain over the entire lip of the cup when the mill is running, the centrifugal force being the active agent in propelling the grain from the centre of the cup over its lip. The flour is taken from the annular space between the stones and case (*C*) by a spout into a conveyer, which conducts it to another part of the mill-house, for separation and packing. Each mill is provided with a lifting apparatus, by which the upper stone may readily be removed and turned over for redressing, and as readily replaced.

The Disintegrating-mill (*pl.* 4, *figs.* 5, 6) is designed for pulverizing grain or unfibrous materials without subjecting them to compression or friction. Some substances, such as superphosphate of lime, contain moisture, and these by crushing become pasty. It was found that when a lump of the material thrown into the air was struck a rapid blow with a stick it became completely shattered, bursting into minute fragments, as though under the action of some explosive force. This principle is applied in the disintegrator by causing pieces of the material to fly radially through it under centrifugal force generated by the rapid rotation of the machine. These flying pieces, being smartly struck by a succession of rotating beaters, the blows being delivered with extreme rapidity in alternately opposite directions, are shattered to atoms by the repeated collisions against the beaters. As the particles struck can offer no resistance but that which is due to their own inertia, without aid from any solid abutment to support them under impact, no compression or friction, as in grinding by stones, is employed, and the moving-power of the beaters is not neutralized and absorbed by any such unyielding abutment. The whole power applied to the machine is utilized in the effort to comminute the material, except that consumed by the resistance of the air and the slight friction of the accessible shaft-bearings. Foreign substances will pass harmlessly through the machine; the beaters cannot become choked, nor can any parts get out of order, since they all revolve entirely clear of one another. When operating upon grain, the beaters run continuously through their interspaces, but not perceptibly near one another; therefore they do not require stoppage or expense for redressing, as do millstones. The beating-force is doubled, because the beaters move in opposite directions, at, say, four hundred revolutions per minute. Each individual grain of wheat is only a fraction of a second in passing the beaters, and in being converted into flour is not heated above 110° Fahr.

This disintegrating-machine is shown in side-elevation (*fig.* 6) and in

vertical section (*pl.* 4, *fig.* 5), exhibiting two circular discs (*A*, *B*), each secured on a separate shaft (*D*, *E*) in the same line, and these discs are driven in opposite directions by belts on either of the pulleys shown. The central solid disc on shaft *D* carries an extension-disc (*A*) studded with five concentric rows of pins or beaters, whose outer ends are secured in rings; intermediate and alternate to these are four similar rows of beaters, secured to the opposite disc *B*, which differs from the disc *A* in having a central opening for the admission of the material. The disc *B* is sustained and carried by the central solid hub (*C*), secured on the end of the shaft (*E*) by two concentric rows of bolts, which permit the passage of all the material from the spout (*G*) radially to the action of the beaters. The beater-pins are of ½-inch round steel pitched to about 2 inches. The grain is delivered through the central opening of the casing (*B*) into the innermost cage by a spout (*G*), which divides into two over the shaft (*E*); the grain is instantly projected through the machine in every direction, and is thoroughly beaten into flour before it escapes from the machine at its outer circumference. Being confined by the case (*F*), the flour falls to the bottom, and is removed by the screw-conveyer (*H*).

Transportable Mills.—It is curious to trace the history of the means by which large armies have been supplied with food. In the early period of Roman history the only article of food issued to the soldiers was grain, which was ground by means of a hand-mill, and this mill was a part of each man's equipment. The modern systems of warfare and the advance in mechanical appliances have led to the construction of more efficient grinding-mills for army service. As an example may be mentioned the floating mills employed during the siege of Sebastopol (1854–55). Two vessels were each fitted up with four mills, which were driven by gears on the propeller-shafts of the vessels. Disconnecting devices were provided, so that the mills could be run while the vessels were at anchor or in berth or the stones thrown out of gear when the vessels were under headway. It is worthy of note that grinding was successfully performed, even in heavy swells while at sea, by the same power that propelled the vessels. These mills were built by Fairbairn.

Millstones driven by Turbine-wheel.—Figure 1 (*pl.* 5) exhibits a complete milling-plant, having in working position two run of burrs, which are connected with the usual elevating- and conveying-machines. The mill is driven by a turbine at the base of a timber flume. The shaft of the turbine-wheel, which is extended to the level of the millstones, carries two small pulleys having direct belt-connection with the pulleys on the mill-spindles. A third pulley drives a vertical shaft, which transmits power to the elevators, conveyers, etc. As the individual parts and their combination are so clearly shown by the illustration, an extended description is unnecessary.

B. ROLLER-MILLS.

Historical.—According to Rhys Jenkins, the earliest record of the use of rolls for crushing corn, etc., is that made by Samuel Hartlib in 1651.

In 1721, John Mortimer invented a roller-mill which consisted of a pair of iron rolls, about 4 inches in diameter and from 18 to 20 inches in length, enclosed in a casing and run at different speeds; this mill was used for crushing malt and for the manufacture of flour, and many machines which were employed for the same purposes were constructed from Mortimer's model. Before the close of the eighteenth century roller-mills were extensively used for crushing oats, beans, and malt. Worthy of especial mention is the one devised in 1774 by Samuel Watson; this was designed for grinding wheat between a central roll and a "breast" (see *pl.* 7, *fig.* 3), and, with the addition of a small roll to the central roll, for crushing oats and malt. In 1775, Rawlinson combined a pair of metal rolls with a pair of stones or metal discs, thus effecting both roller-crushing and stone-grinding.

In 1810, Williams first employed the weighted-lever pressure arrangement. The patent of Parsons and Lambrook embraced circumferentially-grooved rolls geared to give differential speed. The first three-high roller-mill was that of Plummer (1853), who also applied springs to the bearings. In 1854, Spiller combined a roller-and-breast mill with the ordinary stones. In 1856, Alexander White highly recommended preliminary rolling before grinding, especially for hard wheat, as "greatly facilitating the grinding process and improving the quality of the flour." In 1862, Buchholz, whose decorticator is described on page 42, invented a series of grain-cleaning-, crushing-, sifting-, and purifying-machines, but, being "a man before his time," his inventions were not then appreciated.

In England up to this period (1862) the rough-and-ready bruising-mill, by numerous ingenious and necessary details, had been perfected and developed into an apparatus which possessed not only niceties of design and workmanship, but also a precision of movement which produced most satisfactory results. Meanwhile, however, according to Henry Simon, the roller-mill had been constructed in Switzerland as early as 1825, the rolls being of iron and having a smooth surface. It was first practically used on a large scale, about 1839, at Budapest, Hungary, and embodied the important principle of differential speed.

In 1873, Frederick Wegmann, a Naples miller, suggested the freeing of the rollers from rigid pressure by fixing the journals of one of the rolls in levers on which a weight would exert a continuous pressure, while it would admit of independent adjustment. Later, in place of weights, adjustable springs were applied, and these are now almost universally used in roller-mills. Wegmann suggested the use of porcelain instead of iron for facing the rolls. Porcelain, however, being a material much finer in texture than burr-stone, cuts the bran too fine for easy separation from the flour. Smooth chilled-iron rolls, on the contrary, do not reduce the bran-particles, but flatten them, thus rendering separation easy. Porcelain rolls, moreover, wear rapidly and are liable to crack, whereas chilled-iron rolls will run for years even in severe work, and when worn can be easily recut at a moderate cost, and will again serve for another

series of years. In Budapest, the cradle of roller-milling, the use of porcelain rolls, after a long trial, has been abandoned, and cast-iron rolls have been almost universally substituted.

In the early roller-mills one roll was belt-driven, while the other was driven by contact only; but, as this was found to impart an uncertain motion, cog-wheels of different diameters were substituted. Finally, skew spur-wheels of correct figure and even pitch were found to produce the best results. The driving of the rolls by belts has, therefore, been discontinued in Europe.

American millers and machinists, always ready to adopt improvements and to introduce new machines, were not slow in discerning the superiority of roller-mills and in substituting them for stone mills. The millstone merchant-mill was perfected in every necessary automatic device and had passed into history before the present century began, Oliver Evans having taken this first successful step. (See p. 43.) Roller-milling began early in the United States. Before 1840 there was issued a patent which embodied the use of rolls for reducing grain. Since the issue of this patent many improvements have been made, and it may be said that the American roller-mills surpass all others in adaptability and ingenuity of construction. Vast merchant-mills have been erected in different parts of the United States, and the manufacture of flour is now receiving the attention which its importance demands.

Operating Principle of Roller-milling.—In roller-milling the wheat is led from the feeding-hopper to a pair of spirally-grooved rolls, which run toward each other at different speeds and are set apart slightly less than the diameter of the wheat-berries, whereby every berry is broken in its passage between the rolls. The process of bolting follows this first breaking of the wheat, which is then led to another pair of rolls, having finer and sharper grooves and working closer together than the first pair. These second rolls break the grain still finer, the resulting product of the second breaking being sifted and led to a third pair of rolls (having finer and sharper grooves and being closer set than the second pair), by which it is further ground and sifted until all the interior portion of the grain is separated from the bran. The roller-mills are therefore so arranged as to increase the pressure on the wheat at each successive cracking, and by reducing the size of grooves of the rollers all the flour-bearing particles are gradually scraped from the bran. The chief object is to avoid the production of any flour during the successive breakings, and to preserve as much as possible the interior of the wheat in the form of gritty fragments known as "semolina" or "middlings," from which the flour is produced.

The Noiseless Four-roll Roller-mill (*pl.* 5, *fig.* 3) is so clearly illustrated that an extended description in detail is unnecessary, although the principal features that distinguish this machine may be given, to enable the reader better to understand its construction and operation. The mill is self-contained upon and within one solid iron frame, thus securing

stability and permanent adjustment to all the working parts. Eccentric swing-boxes are provided for levelling the rolls and for maintaining them in accurate position. The rolls may be thrown apart at will, or, should an ungrindable substance accidentally be introduced with the grain, they will automatically move apart and return to their original position without changing their adjustment. End play of the rolls is prevented by collars on the journals. The adjustable countershaft through the lower part of the frame secures the important feature of differential motion without the use of gears and renders it possible to drive both pairs of rolls from one driving-pulley with one driving-belt. The use of belts instead of gears causes the machine to run without noise. The feeding devices maintain a uniform flow of grain over the entire working-faces of the rolls, which are constantly cleaned by the automatic scrapers.

Three-high Roller-mill.—A three-high roller-mill with smooth rollers is shown in transverse vertical section in Figures 4 and 5 (*pl.* 5). The centre roll runs in fixed bearings; the upper and lower rolls are carried in adjustable levers, for throwing the rolls apart or for independently adjusting each end, and for effecting these adjustments without interfering with the grinding-pressure. Two distinct materials can be treated at the same time; the feed of one material, passing between the upper and central rolls, falls through the spaces between the vertical tubes (*A*) into the under hopper, while the second material is ground between the centre and lower rolls and falls through the inside of the tubes. This arrangement of cross-channels has the appearance, in front elevation, of a gridiron. The principal advantage of three-high roller-mills is that the downward pressure on the central roll is counteracted by an equal upward pressure, so that the friction due to this pressure is eliminated in the bearings of the central roll. There are thus only four bearings under pressure, whereas in the four-roll mill, above described, there are eight bearings.

Modern 200-barrel Roller-mill.—The sectional elevation in Figure 2 shows the arrangement of a modern 200-barrel mill equipped with the latest improved machinery. It is a five-break mill—that is, it has five pairs of fluted rolls for breaking the grain, including the bran-rolls, and uses eleven pairs of smooth rolls on the middlings. The break-separations are made on double scalping-reels (*a*), and the subsequent separations on round reels (*b*) and on the centrifugals? The outfit of this mill consists of eight noiseless double-roller mills, four double scalping-machines, ten round reels, five purifiers, one purifier for coarse middlings, three flour-packers, one 100-bushel hopper-scale, six cyclone dust-collectors, one receiving and one milling separator, and two scourers. Mills of larger capacity—five thousand barrels per day and upward—are equipped on the same general plan, but with an increased duplication of machines.

Conclusion.—In the preceding pages there have been noted the various forms of mealing-apparatus employed from the earliest times, including the more recent automatic and improved methods of manipulating the grain-products, as well as the machines constructed on higher scientific

principles and requiring for their impulsion the employment of great force. The foundation of a philosophical system of milling rests on the structural peculiarities of the grain, from the study of which has resulted the invention of the roller-mill. The greatest advance in modern methods is, however, not only in the substitution of cylindrical rollers for flat stones, but also in the invention and perfection of every mechanical and manipulating detail embodied in the various auxiliary machines, devices, and processes for the intermediate treatment of the product.

The central idea of modern milling is the production of the greatest quantity of pure flour from a given quantity of wheat, or, in the language of the miller, to make "branless flour and flourless bran." Perfect bread can be made only of pure flour, and was first produced by the Hungarian method, as exhibited in the Vienna bread, "which is a smooth, irregularly-rounded, small loaf or roll. It presents a rich reddish-brown crust and a delicately-shaded, yellowish, almost white interior. It is always light, evenly porous, free from acidity in taste or aroma, faintly sweet without the addition of saccharine matter to the flour or dough, slightly and pleasantly fragrant, palatable even without butter, and never cloying on the appetite." There is, however, no secret about its production. The principal constituents are Hungarian flour—that is, pure flour—and press yeast, manipulated with cleanliness, care, and intelligence.

4. MISCELLANEOUS MILLS.

A. MILLS WITH CRUSHING ACTION.

Ball-mills.—The primitive mealing implement is not only the earliest-known grinding device, but is also the simplest form of a ball-mill, whose action is chiefly reciprocatory, though slightly rotary. To grind gold-ore the Coreans of to-day spread it on a level bed of rock, and over it roll huge cobble-stones or boulders. The development of this simple principle of pulverizing is exhibited by the modern ball-mills, which, however, are driven by motive-power through the medium of gears, or pulley and belt, or both, and depend on gravity only for the requisite pressure upon the materials.

The ball-mill (*pl.* 6, *figs.* 1, 2) consists of a number of metal balls confined in a slowly revolving case, which also contains the material to be ground. In the side of the case there is an opening, through which the material is both introduced and removed, and which during the operation of grinding is closed by a door held firmly in place by a bar and bolt. By gravitation the balls seek the lowest position in the case, but the revolving of the case imparts to them a rolling motion, and their weight exerts a crushing effect on the material beneath and between them, and at the same time a grinding action by a sliding contact with one another and with the inner surface of the casing. The quantity of material to be ground at one time is limited, but by prolonging the process any degree of fineness may be secured.

Modified Ball-mills.—An ingenious modification of the ball-mill is

shown in Figure 3 (*pl.* 6), in which a pocketed ring replaces the balls in a revolving case. As the case revolves the ring follows its revolutions, rolling upon the material, which at the same time, entering the pockets of the ring, is scooped up, carried over, and discharged in front of the ring, and is thus repeatedly acted upon until the desired reduction is obtained. A door or opening in the periphery of the case is provided for the introduction and discharge of the material. This machine is called the "silent" mill, because it is driven without gearing, the motive-power being applied by means of a spool on the driving-shaft, in which spool the case fits and on which it revolves by contact.

In the indigo-mill (*fig.* 4) the pulverization of indigo or other substances of like nature is effected by the pressure of a number of smooth cast-iron balls, which, being rolled over and on the indigo, crush it into powder by their weight, and mix it also into paste when the proper liquid is added. Through the medium of the bevel-wheels (*E*) on a horizontal and a vertical shaft rotary motion is imparted to a driver (*C*, *C*), whose pendent fingers push the balls around. Motion is imparted to the machine by hand applied to the crank (*D*), and is regulated by the arm (*F*) with heavy balls at its ends, the whole being properly supported and carried on a wooden framework.

Edge-stone Mills, or Chasers, as they are generally called, are more effective in the pulverization of material, and with continuity of action they have a larger capacity of production than ball-mills. The early mills of this kind were turned by men or animals (p. 31); the force was applied directly to the shaft, which extended beyond the grinding-bed, as shown in Figure 1 (*pl.* 2); they were used for grinding grain and for crushing olives. The so-called "Chilian mill" (*pl.* 6, *fig.* 5) exhibits the rude construction of a chaser still used in some of the more remote districts of Mexico, Central America, and Peru. Modern and more effective forms of chasers are shown on the Plate. Figure 7 shows two heavy cylinders, differently distanced from the centre, which revolve upon a horizontal shaft (*a*) and are guided in their circuit by the vertical shaft (*b*) by which they are driven. A pin in the slot of the vertical shaft prevents the shaft (*a*) from moving laterally, but it is free to move vertically in the box formed on the shaft *b*. This freedom of motion permits the chasers to rise over the material during the action of crushing.

To present all the particles of the material to the action of the chasers—which do not follow the same path, but roll upon annular portions of the bed-plate—scrapers (*D*) are set obliquely on and secured to a cross-bar, which is turned by the vertical shaft (*b*). These scrapers in going around gather the crushed material in the trough (*C*) and push it alternately outward and inward, thus placing it for most effective crushing in the paths of the slowly-revolving chasers (*A*, *B*), which, in consequence of their great weight and the differential motion of the surfaces in contact, exert not only a crushing effect, but also a grinding one. Such machines can be driven by horse- or steam-power through the transmitting mechanism (*c*,

d, e). Figure 6 (*pl.* 6) shows another form of chaser, in which the motive-power is a steam-engine attached to the frame and acting on the bevel-gearing at the top instead of at the base of the machine. In another form of the machine (*fig.* 7) the extremities of the shaft (*a*) are fixed against turning circumferentially, but are permitted to slide vertically in two slotted columns placed outside and clear of the trough (*C*), which is arranged to revolve and to carry the material around and under the peripheries of the cylinders. The scrapers are also immovable. The above-described edge-stone mills are extensively used in various manufacturing processes, especially where comminution and intimate mixture of the materials are required. In expressing oils they serve for crushing oleaginous seeds; in the pottery industry, for pulverizing the earths and stones; in building operations, for mixing sand and lime: they are also employed for the tempering of putty and in the manufacture of drugs, chocolate, etc.

Quartz-crusher.—A singular application of the principle of the edge-stone mill is exhibited by the quartz-crusher, shown in Figure 9. In place of the two heavy cylinders there are three wheels, which have their bearings on a centrally-guided triangular axle, and which are so placed as to roll in and around an annular trough, in which the material to be crushed is deposited. The crushing weight is secured by loading with stone or other materials the circular basin placed above and resting on the wheels. As seen in the Figure, the horses attached give rotatory motion to the basin, which causes the wheels to revolve by contact with the annular trough, and thus to crush the material.

The *Cycloidal Mill* (*fig.* 8) is a peculiar modification of the edge-stone mill (*fig.* 6). The two cones (*E, F*), which are driven by the vertical shaft (*B*) and the arms (*C, D*), move in a circle upon a conical granite bed-plate (*A*). They do not run, however, upon their peripheries, but upon their level ends; hence they actually slide. These cones (runners) are fitted upon the cylindrical pivots of the arm (*C, D*), so that they can revolve and rest with their entire weight upon *A* and the material placed upon it. The resistances upon the diameter of contact to be overcome by the runners being unequal, in making their circuit they revolve at the same time around their own axis, which insures their uniform wear. The entire grinding-apparatus is enclosed in a wooden or metal casing, which keeps the material upon *A* together. The introduction of the material is effected from the centre by means of a hopper placed at a higher level, while the removal is mostly left to the air, which, being slightly set in motion by the rotation of the runners, carries the most finely pulverized portion of the material over the edge of the casing. Hence, by surrounding the machine with a large wooden box, the finely ground product can be collected upon the bottom, and from time to time can be removed. This arrangement, being especially suitable for the production of the finest dust-like powder for pharmaceutical purposes (for example, gum-arabic), is extensively used in drug-mills. The name of the machine is derived from

the cycloidal form of the tracks which the various points of the runners describe.

Roller Crushing-mills.—In the mills shown in Figures 1–3 (*pl.* 7) the grinding-surfaces are cylindrical; two hollow cylinders roll upon each other, as in Figure 1, or a solid cylinder (*A*) revolves in a fixed concave (*B*), as in Figure 3. In the first form both cylinders revolve either at the same speed, though in an opposite direction to each other, whereby they exert only a crushing effect, or at different speeds, whereby a grinding effect is added to the crushing.

Malt-mill.—Figure 1 represents in vertical section a malt-mill, chiefly employed in breweries. The more finely the material is to be ground, the more closely the cylinders are set; so that, as in grinding flour, for which purpose cylinder-mills are now generally used, the circumferences of the cylinders run very near each other. The same is the case with mills which serve for the subtilization of dough-like materials (chocolate-paste, printers' ink, etc.), and whose arrangement is shown in Figure 2. The material contained in the hopper (*a*) passes between the first two cylinders (*b*, *c*), of which one (*c*) revolves at the greater speed. Now, as areas of equal size of the surfaces of these cylinders take along equal quantities of adhering material, it is evident that the larger portion of the latter is transported a greater distance by *c*. A further trituration takes place between *c* and the cylinder *d*, which latter runs at a still greater speed than *c*. The larger portion of the material being transferred to *d*, a third and a fourth trituration take place between the pair of cylinders *d*, *e* and *e*, *f*, until the material is reduced to the requisite fineness, after which it is scraped from the periphery of the last cylinder by the blade *g*.

Concave-bed Mill.—In the cylinder-mill, shown in Figure 3, a solid cylinder (*A*) works in connection with a concave (*B*), the material being introduced into the intermediate space from the hopper (*C*) by the feeding-cylinder (*D*, *E*). The adjusting-screws (*a*, *b*) serve to regulate the interspace between *A* and *B* according to the condition of the material itself and the degree of fineness to which it is to be reduced. By the cylinder (*A*), revolving toward the left (in the Figure), the sufficiently ground material is carried to a funnel-shaped space (*F*), through which it leaves the mill. The arrangement shown here is of interest, as in a slightly modified form it is met with in the so-called "Hollander," used in preparing paper pulp.

The Gates Roller-pulverizer (*fig.* 4) consists of a pair of Cornish rolls inside of and surrounded by a revolving screen, which has elevating-buckets on its inner surface for returning the partly-crushed material repeatedly back to the rolls until it is crushed fine enough to pass through the screen. The machine is simple, compact, and free from noisy and expensive gearing, the whole of it resting upon and secured in line on a strong iron bed-frame cast in one piece. The roller-shells are separate from their shafts, for inexpensive renewal. The rolls are driven separately, but at the same speed, and give a finished product direct from the one machine. The battery of springs gives the desired pressure. The

journals of the rolls are large and well provided with ample bearing-surface and means for lubrication.

B. MILLS WITH GRINDING ACTION.

Conical Mill.—Figure 7 (*pl.* 7) shows a modification of the ancient Roman mill: a massive conical stone revolves in a hollow cone, the material to be comminuted being conveyed through the narrow spaces between the two surfaces either by gravitation or by centrifugal force. A is the hopper, and B is a shaking-spout for introducing the material with some regularity in the space between the runner (C) and the collar-stone (D). This space narrows from above downward, and can be contracted at will by screws, as seen in the Figure. The smaller the particles of material become by attrition, the farther they sink down, until they finally arrive in the annular collecting-reservoir, which (at E) is provided with a gutter for the discharge of the ground product. The runner (C) sits firmly upon the spindle (a), which is rotated by the bevel-gearing (c, d) from a horizontal driving-shaft, which, as indicated in the Figure, can be moved by means of a crank (e, f), or by a pulley, in place of the crank, driven by a belt from a transmitting-shaft. In the first case it is advisable to provide the fly-wheel (b) in order to obtain a uniform motion.

The revolving-shaft of the runner may also be arranged horizontally. In the latter case, however, the velocity of revolution must be sufficiently great to enable the resulting centrifugal force to convey the particles of material from the thinner to the thicker end of the runner. In the same instance the driving by means of belt and pulley is also presupposed. Vertical conical mills were used by the Greeks and Romans (p. 31), though the arrangement was the reverse—that is, with a stationary central cone and a revolving hollow cone. At the present time conical mills are much used for grinding colors, coal, coffee, and other materials. Instead of stone, the two grinding bodies are frequently constructed of wrought iron, steel, or cast iron (chilled), and are generally provided with sharp-edged ribs; so that the grinding effect is supplemented by a shear-like action.

Portable Farm-mill.—One of the numerous portable mills largely used on the farm for grinding the usual grains into feed is the mill (*pl.* 8, *fig.* 6). The cut shows it as having a *tumbling-rod* connection with a horse-power, and is geared 56 to 1. It will grind from fifteen to twenty bushels per hour by one pair of horses. It is fitted with patent double-reduction hardened-iron grinding-burrs, each pair capable of grinding from one thousand to three thousand bushels of grain before renewal becomes necessary. The arrangement, position, and purpose of the parts are so clearly set forth in the illustration that a description in detail is needless. These mills, constructed chiefly of iron and steel, are simple, and are, therefore, easy to operate. The grinding-plates are protected against injury from hard foreign substances by safety-pins of wood easily replaced. The dress of the burrs is such as to avoid clogging, and at the same time prevents the passage of unground grain.

The "Eccentric" Mills (*pl.* 8, *figs.* 1–5), invented half a century ago by James Bogardus, have superseded millstone-mills for a variety of purposes. Their introduction opened up new possibilities in the milling industries and accomplished results never before attempted. The name "eccentric" is derived from the action of the grinding-plates. These plates revolve in the same direction with nearly equal speed, but as their axes are not on the same centre, there is secured an unlimited variety of movements over their entire working-surfaces. Figure 1 shows the concentrically-grooved face of the plate (*b*) surrounding the ingathering curves (*c*) at the centre. Figure 2 is an edge-view of the plates, exhibiting also the pins by which they are driven, and Figure 3 is a plan of the superposed plates. This disposition of the grinding-surfaces admits of an equal pressure over all parts of the plates, which, on account of the longer travel and the free discharge of the materials, give better results in the finished product than do stones run concentrically. When worn, the plates, which are made on the interchangeable system, can be readily replaced by new ones without stopping the machine every few days to recut the stone, as is necessary in millstone-mills. Figure 4 shows a machine which is intended for grinding dry substances; it is called the "dry" mill, in contradistinction from the "wet" mill exhibited in Figure 5. In the former the materials pass through the eye (*c*) of the upper plate (*fig.* 1) to the grinding-surfaces, and escape at the peripheries of the plates within the case, and thence through the spout at the front of the machine. The grinding adjustment is effected by a hand-screw and lever. A weighted lever is further provided for the purpose of relieving the plates should there pass unnoticed substances too hard to be ground. In the wet mill (*fig.* 5) the position of some of the parts is reversed. The top plate is driven and a cylindrical hopper is formed on the upper part of the shaft, which is perforated, and through which the fluid is conducted by gravity from the hopper to the grinding-plates. The material escapes at the periphery of the plates, from which, as it oozes, it is removed by a scraper crossing the joints, and falls into a receptacle beneath.

Corn-and-cob Crusher.—A machine of the well-known coffee-mill type is shown in Figure 7. This machine, which may be driven from above or below, instantly seizes and crushes the entire ear, though it may be adjusted to shell corn, and also to break it in preparation for burr-stone grinding. It has a hopper fitted over its mouth, and a collecting-bowl beneath, with directing-spout; it can be constructed to rotate the nut or runner either right-hand or left-hand, as may be preferred.

The Case Vertical-stone Mill (*pl.* 7, *fig.* 5) consists of an iron case in two sections, which are fastened tightly together by three bolts. The portion of the case to the left (in the illustration), when the bolts and the lower arm of the shaker-rod are removed, may be drawn backward on the rollers, which are seen on the under side of the case. The portion on the right, which revolves on trunnions, may be lowered to the floor, for dressing the stones. The discharge for the mill is on the side of the case (seen

in the cut on the left-hand portion), and at the rear of the machine is the driving-pulley, which is fastened to the steel shaft by set-screws. On two sides of the hopper is a slide for governing the feed; so that when it is desired a partition may be placed through the centre of the hopper and the slides adjusted to feed grain of different kinds and in predetermined proportions. This arrangement is a desirable feature when grinding mixed grains, as corn and oats. The stones are elastically bedded, so as to yield when a hard substance gets between them, thus avoiding injury, but they will not run together should the feed stop. Our illustration is a perspective view of the general construction of the *single* mill.

The Cyclone Pulverizer (*pl.* 7, *fig.* 6), which reduces materials to dust in violently opposing currents of air, consists of two winged propellers revolving in reverse directions in an enclosing case. There is adapted to the upper part of the body of the machine a hopper for receiving the material to be fed to the machine, and also an adjustable feeding-mechanism, which drops the material between the propellers, each of which is fixed upon a shaft extending within the casing of the machine from opposite sides. The shafts are driven by belts in opposite directions at a high speed, thereby creating a "cyclone," which violently dashes the particles to be reduced against one another, thus effecting their complete pulverization with comparatively little wear on the operating machinery. From an opening in the top of the casing of the machine a connection is made with the grading-box and the dust-chambers. This box is divided by partitions into compartments, which are at varying distances from the mill, and into each of which the floating dust drops. As the velocity of the air entering at the propeller-shafts and passing through the case toward the dust-chamber lessens, the heavier atoms of dust fall first, while the slowing current so graduates the product that the finest is carried into the dust-chamber, where in the comparatively still air it is permitted to settle. The mill completely comminutes the most obstinate substances, such as iron-slag, phosphate-rock, silica, and green bones, and is equally effective in reducing oily, viscous, and fibrous substances, such as fish-scrap, clay, soapstone, dried tankage, and blood from slaughter-houses.

The Scientific Grinding-mill (*pl.* 8, *figs.* 8–12) is intended for grinding any kind of grain for feed, and will grind ear-corn with the shucks on or off, reducing the shucks, cobs, and corn all to any desired fineness. Figure 12, which exhibits the front part of the casing cut away, gives a good general idea of the interior arrangement. The material is fed into the hopper and is caught by the lugs on the two rollers, which revolve toward each other, the motion being communicated by means of a gear-wheel engaging a pinion on the main shaft. By these crushers the material is broken into pieces, which fall upon the crushing-conveyer on the main shaft, where they are further broken and conveyed to the grinding-plates shown in Figures 8 to 11. One of these plates is stationary, and the other is attached to, and revolves with, the main shaft. The shaft moves easily back and forth in its bearings; so that the running plate can be set close

to, or away from, the stationary plate by a screw, by which means the grinding will be either coarse or fine, as desired. At the end of the shaft is arranged an anti-friction block, which takes all end pressure, and the bearing at that point is self-lubricating; hence there is little danger of excessive friction. The mill is very strong, and the plates are capable of grinding large quantities of material before wearing out; new plates can be easily and quickly inserted. This mill, of which numerous sizes are made, grinds all small grains, such as shelled corn, oats, screenings, etc., as well as ear-corn, and by it excellent corn-meal can be produced.

The grinding-plates (*pl.* 8, *figs.* 8–11) are of peculiar construction or *dress*, which makes them particularly valuable in respect to the quality of the work they will do. The principle is that of gradual reduction. On the running plate and close around the shaft are large ribs, which lack less than ½ an inch of coming in contact with the corresponding ribs of the stationary plate; then come numerous small A-like projections (*A*; *fig.* 8), and finally, on the outer edge (*B*), a ring of fine reversed inclines. The ribbed plates engage the grain, small pieces of cob, etc., which have been broken by the double breaker and further reduced by the crusher, and reduce them to small uniform pieces. The material then passes to the plates at *A* (*fig.* 9), whose sharp-edged projections cut or shear the small pieces of grain, etc. as they pass from one to the other; and finally the material, now reduced to small gritty particles, is taken by the corrugated edges of the plates and is rubbed to the desired quality of feed. These plates are made of very hard cast iron; and when worn, the direction of running them may be reversed, which brings into service their opposite edges. This mill, therefore, possesses in one form the self-sharpening principle.

Cutting-surfaces of Rolls.—We may observe at this point that, as every cutting-tool implies an adjoining void, the cutting principle in millstones is due to the hard edges of porous substances. Thus, French burr-stone and the various forms of lava and sandstone of which the ancient and modern millstones are made have these characteristics, and those kinds which are the hardest are the most highly prized. Even fine-grained porcelain, which has been used in the rolls of roller-mills, has been found, on trial, to possess a cutting-surface too sharp for the bran-particles, which are too much reduced for easy separation from the flour, and these rolls have for this reason, in certain milling-plants, given way to chilled-iron rolls, which have smoother surfaces, and which cut and wear less. (See p. 47.)

The Self-sharpening Principle, in so far as it depends upon hard and soft materials alternately arranged, is illustrated in the conformation of the crowns of horses' teeth and of those of other grain-eating animals, and in the teeth of beavers, which are admirably adapted for cutting wood. The convolutions of the projecting harder portions of the crowns, from which the softer intervening matter has been worn away while masticating grain, are shown in Figure 13 (*pl.* 8), and in Figure 14 is exhibited a cross-section of a tooth which has been surfaced, and from which the

dentine has been partly removed, thus showing the ramifications of the enamel.

Natural Crushers.—In the solution of numerous mechanical problems Nature furnishes many suggestive examples. We may refer, by way of illustration, to a natural crusher—namely, a lobster's claw (*pl.* 8, *fig.* 15). This consists of two hinged parts so formed as to possess great power and wonderful adaptation to the purposes intended. The general appearance suggests the parabola, which is the favorite and usual shape adopted by the scientific mechanic and proved by mathematicians to be a form possessing the greatest strength and resistance with the least amount of material. Further examination in detail will reward the student with natural examples of the best disposition of material, of adaptation of means to an end, of protection to delicate parts, of marvellous joints and means of operating them, the whole being managed at arm's length, delicately hinged and folding, prehensile, and of unusual interest to the constructing mechanic.

(J. H. C.)

II. PRESSES.

Presses assume a great variety of forms in different mechanical processes. They are employed (1) to compress bodies into small space, as in the packing-press; (2) to increase their dimensions in a particular direction, as in the roller-press or roller-mill; (3) to divide substances either wholly or partially, as in the cutting-press; or (4) to impress substances with figured designs, as in the stamping-press, etc. The machines by which these several operations are effected can be better explained in connection with the different manufactures. Custom, however, has so limited the term *press* that it does not apply to all the machines in the above classification, but, as a rule, only to those which act by means of a lever or a screw, and to the hydraulic press of Bramah (*q. v.*). We shall therefore describe those machines, not elsewhere noticed, which are employed for compressing materials for purposes of extraction, as wine-, oil-, and cider-presses, and those for compacting substances, or formative presses, such as baling-presses, etc., of which examples will be given illustrating the acting principle of the lever-, screw-, toggle-, and hydraulic press.

Wine-presses.—Most races of mankind have possessed the secret of making some kind of intoxicating drink. The Biblical wine-press was simply a vat, usually about 8 feet square and 4 feet high, with a grated opening near the bottom, through which the juice of the fruit ran into a vessel beneath. The juice was expressed by the bare feet of one, two, three, four, or even five, men, who tramped the fruit in the vat, staining their legs and garments with the color of the "must." The wine-presses of the ancient Egyptians, as depicted on their tombs, were of various kinds: in one form the grapes were put in a bag and squeezed by twisting the bag in opposite directions; another plan was to place the fruit in a cloth, which was twisted and strained by means of a pole at each end in the hands of a number of workmen (*pl.* 9, *fig.* 1). The Romans employed several methods for expressing the juice. The grapes were usually crushed beneath a wooden beam or in a press whose platen (*prelum*) was driven down upon the bed (*torcular*) by wedges. Sometimes a lever was used for the purpose, and in a Pompeian painting there is seen a press having a pair of screws. The treading operation was also common, and is represented in a mosaic of the temple of Bacchus at Rome; it is substantially the same as that of the Syrian wine-press of modern times exhibited in Figure 2. In some parts of France and other wine-producing countries of Europe the old plan of treading out the grapes is still in vogue.

In the vineyards of California presses of great power are employed. One form consists of a press-box, 6 feet square by 4 feet deep, in the sides of which small interstices occur for the escaping of the must. The follower or platen is moved by an iron screw 6 feet long and 5 inches in diameter, having a slow pitch, which is said to exert a pressure of 282,000 pounds. The press is filled with alternate layers of crushed grapes and 3-inch wooden cubes, every 6 inches of grapes being followed

by a layer of cubes. Figure 3 (*pl.* 9) represents a simple toggle wine-press which is operated by two ratchet hand-levers for the flexion of the toggles.

Cider-presses.—Figure 4 shows the simplest type of cider-press, which is a lever-press consisting of a long beam (lever), a press-box, and a bed. The lever, which is fulcrumed at one end to heavy posts, imparts the pressure by means of heavy weights placed on the other end, or, as in the Figure, by movable bars and pins, alternately actuated by a short hand-lever. The press-box, which is provided with interstices for the escape of the juice, is substantially made, and is supported on a solid bed of sufficient height to allow a vessel to be placed under the press to receive the expressed juice. The crushed fruit receives at first a gradual pressure; as the pomace becomes compacted or the action of the lever becomes inoperative the latter is raised, and heavy blocks of wood are laid on the press-cover or platen, whereupon the lever is again lowered and the pressing is completed. The modern hand cider-press usually combines a grinder and a press in one frame, the platen being operated by a direct-acting screw (*fig.* 5). Until within a very recent period cider-presses have been worked almost exclusively by hand. Hand-presses have largely been supplanted by power-presses of the knuckle-joint, or direct-acting-screw, type. For heavy and continuous work the latter press has four vertical screws, one at each corner of the press-frame. The pressure-beam is operated from each end by screw-nuts actuated by spur-wheels that receive their motion from a cog-wheel on a vertical spindle, which engages with two spur-wheels and is turned by a bevel-wheel gearing at the top of the press. It has three rates of speed—fast, medium, and slow—which enables the operator to run the head down rapidly until it strikes the cheese, then to shift to the medium motion, until most of the cider is extracted, and to finish on the slow speed, the power increasing as the speed decreases.

Oil-presses.—In the East, where vegetable oil forms an important article for food and for other personal and domestic purposes, various ingenious applications of lever-presses and of combined lever- and wedge-presses have been employed from the earliest times. The most ancient presses for extracting the oil from the seeds of various plants were those for expressing the oil of the olive, and were used in Palestine at a very early date. The preliminary crushing of the olive was done by means of the so-called "Chilian mill" (*pl.* 2, *fig.* 1). The oil-press in use at the present day in Syria and Palestine is substantially the same as that used by the Phœnicians in the time of Solomon. It consists of two upright posts connected at the top by a heavy cross-piece or lintel. The mashed fruit, in straw baskets, is placed on a bed-piece and the platen adjusted, upon which there is laid a beam whose ends slide in grooves on the inner faces of the posts as the beam is pressed down by a lever above. This leverage requires the heavy lintel to resist the upward thrust of the lever. The oil-press of the Romans, which, according to Pliny, was an invention of Aristæus the Athenian, was of similar construction. Pliny describes in detail the

apparatus and processes employed for obtaining olive-oil, and from him we learn that the Romans derived from the Greeks a knowledge of the screw-press, and that they used it to express oil from pulped olives.

In modern times the flax plant has constituted the largest source of supply of the oil-bearing seeds, but within the past few years cotton-seed has also been found to yield a large quantity of oil. The apparatus formerly used in Europe for expressing oil consisted of forms of wedge- and screw-presses and of the Dutch or stamping-press, an invention of the seventeenth century, all of which have practically been superseded by the hydraulic press. The wedge-press is a powerful though somewhat crude machine. The crushed seeds are contained in hair bags, which are placed between vertical perforated-iron cheek-plates. The space between the plates is occupied by blocks and wedges, which are tightened by driving in the tightening wedge with a maul. Time is allowed for the oil to exude, when the pressure is removed by means of an inverted or loosening wedge. Screw-presses were eventually substituted for the wedge-presses, and the Dutch press long played an important part in the oil industry, but the hydraulic press is now the main dependence.

Packing-presses for compactly baling for transportation substances of considerable bulk, such as cotton, wool, hay, etc., are of numerous varieties. They are either of the screw, toggle, or hydrostatic type, and may be actuated by hand-, animal-, steam-, or other power. The simplest form of packing-press consists essentially of a bed, vertical rods for the support of the press-head or enclosing sides, and a platen or follower, which is moved vertically downward, as in the screw-press (*pl.* 9, *fig.* 8), or upward, as in the hydraulic press (*fig.* 9). Figure 10 (*pl.* 60) gives an example of a hay-baling press which is operated by horse-power, and which is fully described on page 190.

Differential-screw Packing-press.—The power obtained by the use of a screw may be increased either by lengthening the lever or by increasing the number of threads in a given space—that is, by making them very fine. There is, however, a limit to the employment of either of these methods, for by increasing the length of the lever the machine becomes unwieldy, and the finer the threads the weaker they become. The differential screw, invented by Dr. W. Hunter in 1781, obviates these difficulties. It uses two screws of different pitch on the same shaft, the operation of which is analogous to that of the Chinese windlass (*pl.* 108, *fig.* 10), whose barrel has two diameters, the rope unwinding from one as the other winds the rope. This principle is applied to the press shown in Figure 8 (*pl.* 9). The presser or platen is urged downward by the screw having the greater pitch, while that with the smaller pitch draws back to an extent corresponding to its pitch. Thus during each revolution of the screw, instead of advancing the action through a space equal to the pitch of either of the threads, the platen is moved a distance equal only to the difference between the two pitches, and the mechanical power is therefore equal to that obtained from a single screw having a pitch

equal to this difference. In this way pressure is obtainable to any extent within the practical limits of the difference between the pitches of the threads.

Toggle Packing-press.—A machine introduced as a mechanical substitute for the hydraulic press is the Boomer press (*pl.* 9, *fig.* 7). It consists of a combination of four levers or arms working upon toggle-joints, through which passes a right- and left-handed screw, whose rotation causes the two joints either to approach or to diverge from a central line according to the direction of such rotation, with a uniform motion. The sliding standard extends through the top frame or head-block, and keeps the pressure-plate in its true horizontal position, controlling the power and preventing endwise motion of the screw. The entire pressure is not thrown on the threads of the screw, but is transmitted through the toggle-joints to the head-block, which is connected with the base by wrought-iron standards or posts. The power is applied by first running down the platen by the hand-wheel at the end of the screw until the heaviest pressure is attained, and the final pressure is applied by means of the lever and ratchet-wheel in the centre. It is claimed that with this machine one man is able to exert a power exceeding that of five men with the ordinary screw.

Hydraulic Press.—The introduction of the hydraulic press effected a revolution in the various industries requiring compressing or expressing machines. It was invented in 1795 by Joseph Bramah, an English mechanic, and is usually designated the "Bramah" press. It is a machine in which the pressure of a piston on a body of water of relatively small sectional area is made to transmit the force to a cylinder of multiple area. The principle on which it acts is founded on one of the fundamental laws of hydrostatics—namely, that any non-elastic fluid, such as water, possesses the property of transmitting pressure exerted against it at any point equally in every direction. The operation of a hydraulic press will be comprehended from the following description of the illustration (*fig.* 9): *a* is a reservoir of water, on which are the pumps (*b*), whose piston-rods are worked by hand-levers (*c*). The water is conveyed by the pipe (*d*) to the cylinder of the press, where it elevates the piston and table (*e*), which rises between guides that hold the upper plate or presser-head, against which the substance under pressure is driven. The elevation of the table is proportionate to the quantity of water injected, and the pressure exerted is in proportion to the respective areas of the pump and the cylinder.

The hydraulic press is adapted for a great variety of purposes in which a high and permanent pressure is required. Modified forms of machines, on the principle of the hydraulic press, have of late years been largely employed, and for a great variety of purposes that formerly were not thought of. Water, being nearly incompressible, is a convenient mode of conveying power to a distance, and in many cases of applying the force directly to machines. Hydraulic power is used for working lifting-jacks, cranes, punching- and riveting-presses, etc., for engines as

motors, and for operating warehouse hoists and passenger elevators, all of which are particularly described in the following pages under their appropriate heads.

Hydraulic Cotton-compress.—The constant increase in the production of loose materials, such as hay, cotton, etc., at a distance from the centres of their consumption, has led to the construction of special apparatus for compressing them into packages which can be more easily handled, more cheaply transported and stored, and be sold at more remunerative prices than if shipped in bulk. Several presses that have been invented in recent years are rendering efficient service to agriculture and the industries. This is especially evidenced in the baling of cotton (whose production in 1888 reached the large number of 6,935,082 bales), for which purpose the hydraulic press is eminently adapted. Figure 6 exhibits a powerful hydraulic cotton-compress operated by steam. This machine consists of a cast bed-piece with housings which support the press-head or upper platen, on which rests the hydraulic cylinders. There are three cylinders, each $26\frac{1}{8}$ inches in diameter, with their rams or pistons working upward. These rams raise a cross-head to which is attached strong steel links carrying the table or lower platen. The water, on being forced into the hydraulic cylinders of the press, raises the ram-heads, which in turn raise the cross-head and lower platen, on which is placed the cotton-bale, and compresses it to the required density against the press-head. To operate the press there is provided a high- and a low-pressure steam-engine cylinder; to each cylinder there is attached a hydraulic ram, both rams being connected with the press cylinders by means of a pipe for transmitting the water. The low-pressure steam-cylinder has a diameter of 73 inches and a stroke of 10 feet; the high-pressure cylinder has a diameter of 73 inches with a stroke of 11 feet, and uses steam at 125 pounds per square inch. The high-pressure ram has a diameter of $13\frac{1}{8}$ inches, and the low-pressure ram has a diameter of $29\frac{1}{4}$ inches. The initial pressure is given the bale by the ram of the low-pressure engine; the high-pressure engine ram is then brought into action, by which the pressing of the bale is completed, with a total pressure on the bale of 3000 tons. There is thus obtained a power sufficient to permit of furnishing in a compact form a bale of 500 pounds and of a density of 50 pounds to the cubic foot. The capacity of the machine is one hundred bales per hour.

Hat-press.—All fibrous substances possess to some degree the property of being shapable—that is, the elementary fibres, and hence, also, the fabrics produced from them, assume under the action of heat any shape imprinted upon them, and retain it with a certain consistency. Of this property, which is also taken advantage of in ironing and pressing wash-clothes, the hat-press (shown in Figure 10) makes excellent use. It serves to give to felt and straw hats the shape prescribed by the prevailing fashion. The press contains a cast-iron mould with thick sides heated from below by a charcoal fire or by gas, upon which the hat is placed and then pressed uniformly on all sides by an elastic membrane—the so-called

"gum bag." The latter consists of a thick sheet of india-rubber shaped like a hood, which assumes the shape of the hat. The edges of this sheet are secured to a hemispherical metal lid in such a manner as to allow of a very high pressure (twenty to thirty atmospheres) being brought to bear upon the back by means of water-pressure. The water is forced into the dome by means of a small hand force-pump, and compresses the film on the hat and presses the latter on to its mould. In the figure the lid is shown turned up, in which position the hat to be shaped can be introduced. Before the production of the high pressure the lid is turned down and closed with a strong bolt. Since the introduction of this machine the former customary pressing of the hats upon the mould has been almost entirely abandoned.

III. SAWS.

Historical.—The saw, which is an ancient, useful, and familiar tool, has a history of its own. When we speak of a saw, we generally mean a tool for dividing wood, although the saw is used for other solid materials, and, moreover, has other uses than mere dividing. Thousands of years ago the Egyptians were acquainted with and used this tool, which was made of their celebrated bronze hardened by an art that for ages has been lost, as also have been many other arts employed in the daily work of those who dwelt in the land of Egypt. The supposed originator of the saw, Talus or Perdrix, was deified by reason of his invention, which was great because of its prime importance in building and ornamenting homes and articles of furniture, as well as vessels and vehicles, by which the brotherhood of man could be more firmly established and his wealth and power increased. But probably the introduction of this useful implement was not confined to any one inventor or originator. The idea doubtless suggested itself to hundreds of ingenious savages in many widely separated portions of the globe, where the material employed, the style, and the method of its use, were equally diverse. The most primitive saw was probably made of a jagged piece of stone or shell; later on there was employed a wooden handle with a cutting edge of sharp teeth or of similar cutting or rasping points, which worked their way through woods of various degrees of hardness at a rate depending upon the material and upon the strength and patience of the workman. In the Stone Age saws were made of wood with flint teeth. The Mexicans six centuries ago used long pieces of obsidian (a black stone sometimes called "natural glass"), the edges of which they had notched.

From the primitive and ineffective saw of stone, shell, or fish-teeth, through the period of the bronze plate with filed teeth, to the modern iron or steel saw, is a long step. A collection showing the successive and different manners of holding and working the blade would be exceedingly interesting. Each decade within the recollection of men not yet old has brought fresh advances in the manufacture and fresh triumphs in the use of this important industrial implement.

The Pit-saw (*pl.* 10, *fig.* 5) was so called because its use required one of the operators to stand in and the other over a pit, across which the log or tree was laid. The blade was tapering, and cross-handles were attached for working the saw. The lower man or pit-man (from which originates the name given to the rod which connects a reciprocating with a rotating object, as that which couples a crank with a saw-gate) stands behind the blade to avoid the dust of the saw, which cuts on the downward strokes. The pit-saw was crude and defective, its principal fault being a degree of slowness which in its time was scarcely noticed, because there was then nothing, and little thought given to anything, more rapid.

Hand-power Saw-mill.—A more ambitious device is the board-mill shown in Figure 1. There are two hand-wheels (*A*, *C*), to which rods

(DM) are attached for working the frame E, which is pivoted in the main frame and works the saw-frame up and down. On the upper end of this framework there are provided braces (FG), to which the saws are secured according to the number and thicknesses of boards required. The timber K is placed on rollers, and each time the wheel at H is struck by the projection B on the wheel A, the log is moved forward; a strong rope or chain fastened under and at the end of the block K fastens itself over the axle of the wheel, and whenever the projection B of the wheel A grasps the former wheel at H, the timber is drawn forward for sawing.

Tread-wheel Power Saw-mill.—The mill shown in Figure 2 (*pl.* 10) may be operated by one or two persons by means of a tread-wheel (A), to the beam of which there is attached a "trillis" (C) with strong spindles, and by this is turned the cog-wheels D and F, D moving on the spindle E, and F on the spindle C, the spindle E being attached to the centre of the cog-wheel F. To the spindle E is attached the beam Q, which, by means of the crank P, moves the perpendicular bar that connects the saw L and its horizontal beam (M) upward and downward. The horizontal beam M is set in the grooves N, N, and the timber to be sawed is fastened with clamps in the rolling framework K, at the end of which there is attached a strong rope drawn over the roller O and wound on the wheel I, which is held in place (or held back) by the inclined bar or arm H.

Animal-power Saw- and Flour-mill. — Figure 3 is a combination of saw- and flour-mill operated by animal-power, and of interest to those who follow the history either of sawing or of mealing processes. As will be seen, it may be arranged so as to be used both for sawing lumber and for grinding cereals. The upright beam A with its horizontal cog-wheel is driven around by the animal (as shown in the cut); a cog-wheel connects with the spindle of the trillis B, and by that means drives the other upright beam H, to whose lower end is attached a double cog-wheel (C); the upper cogs move in the trillis D (on the right) and the side cogs in the trillis F (on the left), the latter operating the millstone G and the former operating the wheel E, which by its connections at L operates the saw M below, thus giving actually two mills operated by one means of power. At the upper end of the beam B is placed the large wheel I, to which three (not four) heavy weights (K) are suspended; this is done both to obtain increased power and to relieve the strain on the animal.

Water-power Saw-mill.—Figure 4 represents a primitive saw-mill used for cutting large trees into planks or boards; it is driven by water-power, and can be erected and operated on the banks of a stream. The wheel Z is the main motive power; to this is attached a curved arm (X) which is fastened to a horizontal bar (T), with uprights running through the grooved or slide-frame S, S, having on the top thereof a cross-bar, to which the saw is attached. The wood W to be cut is fastened with wedges on an elevated platform between the beams XX, and the up-and-down motion of the arm X produces the sawing.

Classification.—Saws, considered with reference both to their blades and to the machines that drive them, may be divided mainly into two classes: (1) reciprocating and (2) continuous-acting. In the first division the saws that act alternately or with a reciprocating motion have straight, or nearly straight, blades. Saws with straight blades may be subdivided into those held at one end only and those held at both ends, the former including those that cut upon the pull-stroke only, those that cut upon the push-stroke only, and those that cut upon both. There are three varieties of continuous-acting saws—namely, (1) band or ribbon, (2) circular or disc, and (3) cylindrical or tubular. With these may be included spiral and chain saws, which are in some measure varieties of the band, and the spherical-segment or dished-circular saw, a variety of the circular proper or flat disc. Cylindrical or tubular saws are of two kinds; one of these acts at right angles to the plane of the material to be cut, as in the case of the trephine or trepanning-saw used in surgery to cut a disc out of a skull, while the other, the barrel-stave saw, acts with its axis parallel to the length of the piece to be cut, and produces a stave-like piece with one side concave and the other side convex. The spiral saw, used principally for dovetailing, is a cross between the band- and the circular saw. A large part of its work is widening with one portion of its cutting-edge the kerf made by that part which precedes it. Circular saws may be divided into those set with their discs or planes at true right angles to their axes or arbors and those having a slight inclination, which causes them to "wobble" in running.

Saws may also be classified into those used singly and those employed in gangs. Both straight and circular saws are used in gangs having several sets of parallel cutting-edges, and furthermore circular saws are also so mounted that instead of having several saws upon one axis there are two or more on different axes. Two band-saws may also be arranged to make parallel cuts.

Saw-teeth.—In some saws the teeth are cut out of the solid blade or disc, whose effective diameter becomes diminished as the teeth wear down, while in others the teeth are inserted (*pl.* 10, *fig.* 6), and when they are dulled or damaged may be removed and others substituted. Between inserted- and solid-teeth saws there is a middle variety with removable segments (*fig.* 7), each bearing several teeth, so that any one segment, if damaged, may be removed and another substituted; and when all the segments are worn out, they may be exchanged for a new set, leaving the effective cutting diameter the same as it was originally. Moreover, one centre may have several sets of segments, by means of which the saw may be given any one of several effective diameters.

Aside from the use of saws for cutting stock in two or more pieces, a very important application is for "crozing" or "gaining" (cutting grooves), particularly in barrel-, vat-, and tank-work.

Unstrained Saws.—Sawing-machines employing straight blades may be divided into "strained" and "unstrained," the former being held at

both ends and the latter at one end only. Of those with unstrained blades the "drag" and the "mulay" cut upon the pull-stroke only, and need no guide, because the greater the resistance, the more taut the blade is pulled.

The Drag-saw, which differs from the mulay in being horizontal, while the latter is vertical, answers well for cross-cutting logs and for cutting staves, heading- and shingling-bolts. As its tip is not guided in a straight line, but is free to describe an arc, the blade is generally a practical prolongation of a crank-driven pitman. In the ordinary cross-cut saw the feed is effected by gravity only, the blade commencing at the top of the log and gradually working through. In one form (*pl.* 11, *fig.* 1) the crank-disc is arranged between the log and the pitman cross-head, thus giving a very long reach to the rod bearing the saw. In one of the most convenient drag-saw machines the blade may be drawn up out of the way when through, ready to be lowered for another cut; and, as the crank-pin is attached to the disc, and is also adjustable, the "throw" may be varied. The drag is used principally for cross-cutting logs, and one variety, fixed to the cross-head of a small steam-engine, is made in Europe for felling trees by sawing them through close to the ground (*pl.* 10, *fig.* 8), the blade lying flat and the feed being effected by a special mechanism which gradually swerves the entire machine in a circular arc. It may also be arranged for ordinary log cross-cutting.

Strained Saws.—There are more varieties of strained saws than of unstrained, the former class being divided into (1) those kept in tension by a spring and (2) those strained in a gate or sash, and hence having a positive pull which is practically unvarying each way.

Spring-strained Saws, which are of small size, are generally used for cutting curves in thin stuff. Of this type are the "scroll-," "jig-," or "fret-" saws, which may have either (1) a plain wooden lever, (2) leaves of steel fastened at one end, (3) a regular leaf-spring held in the middle, or (4) flat spiral springs whose axes bear levers having fastened to them the levers attached to the saw cross-head. In some power-driven machines, where the blade is held at both ends, the strain is greatly variable during the stroke, as the tension is put upon the blade partly by the amount of pull upon it and partly by a spring, which may be a simple lath or a more complicated leaf, attached at that end which would be called the tip of a pull-cutting saw. In either case the work to be done is the same: keeping the blade as nearly as possible at the same tension during the entire cutting-stroke and preventing it from buckling and fouling during its return. Some jig-machines have the table and bed separate from the guides and from the tension device, while in others the cross-head is driven by a pitman from a shaft below. For cutting bevelled lines the table needs to be pivoted and should tip in a plane revolving about an axis that will make it form an angle with the side of the saw; so that, as the operator stands facing the saw-teeth, the table tips either to the right or to the left. Both ends of the blade may be much more effectually held in a "frame" or "sash." In this case the tension, usually given by taper-keys or wedges,

is applied permanently to the blade of the saw, any variation being that caused by the buckling of the cross-members of the frame.

The Gate-saw is practically the same as an ordinary single-blade sash-saw, but the gate is much wider in proportion to the length of the saw and stroke, taking in from 64 to 84 inches swing for a thickness of 6 inches of material sawed and having a stroke of from 4½ to 5½ inches. Such a machine (*pl.* 11, *fig.* 2) has the gate driven from both sides (or ends) by pitmans from an overhead shaft.

Gang Sash-saw.—In lumber-sawing it is important to save both material and labor. Circular saws, on account of the width of the kerfs they cut, waste too much material, and as they cannot be made with thin blades, and as not every one can run a band-saw, the gang sash, by reason of the extremely thin saws it can use, offers the best means not only for saving material (in which respect it is equal, if not superior, to the band-saw), but also for saving time and labor by making several cuts at once, in which latter respect it has the advantage of the band. But the ordinary gang sash is a reciprocating machine which if not properly balanced will shake itself to pieces and endanger its surroundings. Increase of weight, required for heavy sawing, only makes the matter worse; for, if unbalanced, the heavier it is made the weaker it is. In one type of compensating gang the sash (*fig.* 3) and blades are counterbalanced by a weight attached to the opposite side of the crank; the weight of the two pitmans driving the counterpoise is equal to that of the pitman driving the sash, and the counter-weight exactly balances the sash. As one pound goes up another goes down with the same velocity, and the mill runs smoothly. The machine is self-contained, and it is claimed that if set upon the beams of a mill it will run quietly at three hundred revolutions per minute. One disadvantage of the gang sash is that when sawing cants which are slabbed only top and bottom there is no opportunity for selecting from the face of each cut the best clear stock, the sawyer being likely to let the best of the log go to form part of each board, the grade of which may be lowered by knots and shakes, whereas were they sawed off separately with a circular or band-saw he could pick "the fat and the lean."

Fret-saws.—For some purposes a jig-, scroll-, or fret-saw is better than a band, as it will make both inside and outside cuts; furthermore, the band-saw table, tilting but one way, allows draught upon one side only, while the jig gives draught all around. As a thinner blade can be used on a jig- than on a band-saw, the former will do curved work more smoothly and accurately, and less time is required to start and stop a jig- than a band-saw. To secure greater rigidity in machines having the table separate from the upper part, the guys, tightened by turnbuckles, are extended from the lowest possible point of the vertical post to points upon the ceiling. In jigs it is desirable to have at all points of the stroke an equal strain upon the blade, and to be able to vary the tension. In some machines the deflecting strain is produced by two steel springs (each made of a series of graduated lengths), to one end of each of which are attached

straps extending to a segmental pulley. As these straps are wrapped around this pulley, the leverage is lessened as the strain upon the springs is increased, thus compensating for the distance the saw travels (*pl.* 11, *fig.* 4). The deflecting springs are attached in a sliding cross-head adjusted to suit the thickness to be sawed. In jigs, if the blade is held in a clamp, it will be unnecessary to punch or drill holes in the blade, and this is also an advantage when using broken blades (*fig.* 5). In one make the upper end of the blade is held in a clip attached by a link to the outer end of a lever with its other end keyed upon a shaft bearing a strong flat spiral spring; this single lever lies in the plane of the saw and about at right angles to its length. Where there is a spring-head it is desirable to have it slide on the standard, so that the same strap-length may be used for blades of different lengths. The hold-down and the slides should be adjustable independently of each other for thickness of stuff and for length of blade. To keep the teeth cool and the working-line visible, every jig should have a blower provided with a rubber tube, to conduct the air to the saw-kerf, while some of the blast may be directed against the lower guides, to keep them cool and free from sawdust. As on inside work it is necessary to stop and start frequently, some machines have instead of fast and loose pulleys a friction-brake, which will save about half the time on such inside work, while in others the machine can be stopped when running at full speed, and the blade can be quickly removed and replaced. An unstrained or "mulay" jig does not hold the blade at the top, but simply guides it. Kept close to the work is an adjustable guide, which holds the sides and back of the blade between steel plates adjustable to the thickness of the different blades used. There being so little reciprocating weight, such machines are adapted for use on the upper floors of buildings.

Circular-saw Machines may be considered in accordance with their construction rather than with reference to their uses or size. The methods of holding and driving the saw-discs are many. The saw may be (1) upon a fixed arbor, the stock or work being fed by hand along a guide; (2) upon a fixed arbor, the stock being fed upon a carriage; (3) upon a movable arbor swung in a frame, the saw being brought down upon and thrust through the work; or (4) upon a movable arbor mounted in a sliding carriage, the saw being fed through the stock. The disc may be set (1) at exactly right angles to the arbor; (2) a trifle out of square, so that it will cut a groove wider than the extreme distances between teeth sides; or (3) very "staggering," so that it will cut a "gain" or groove.

Machines with mandrels having only a rotary motion may be divided into those (1) in which the table has no motion nor adjustment, (2) in which the table tilts in a plane at an angle to the saw-arbor, and (3) in which the table or carriage slides. The saw-arbor is either fixed or movable, and may receive its rotation from hand-, foot-, or horse-power, or it may be belt-driven or "direct-driven" by a high-speed engine.

Machines in which the mandrel moves in effecting the cut may be

divided into those (1) in which the arbor is in a sliding frame and (2) in which the material is in a swinging frame. If arranged in gangs, circular saws may be (1) very close together, and may be used as rippers to make a great number of thin pieces, as laths; (2) quite far apart, used to bring boards or timbers to a given width; or (3) a considerable distance apart, used as cross-cuts to bring to a fixed and uniform length pieces passed between them. Two parallel circular saws may be so arranged in connection with two cross-cutters as to form a "square tenon" (*pl.* 12, *fig.* 4), or one circular may work so as to form a round tenon upon the end of a rotated slat.

Gang Ripping-machine.—In ordinary use a gang ripping-machine (*pl.* 11, *fig.* 8) has upon the arbor at the same time but two saws, one fixed, the other movable, with an adjustable guide-bar; but these two saws may be made the equivalent of three by governing the loose or movable saw with one lever and the guide with another, each having an index which gives accurate measure. In an improved self-feed gang rip-saw of the three-disc type, the operator with one lever manages the movable gauge upon one side, and with another lever controls the position of the shifting saw; so that he can rip stock either of one width or of different widths.

Double and "Three-high" Circular Log-mills consist of two or three saws, respectively, one above the other, with parallel axes; but when three discs are employed it becomes necessary to have a fourth, with a vertical arbor, to divide the board for the passage of the mandrel of the middle one. Double circular mills may be constructed with the top saw either mounted in one frame with the under one or carried by an inverted hanger separate from the lower frame; the latter being a very good way to make a double mill out of a single one. In this case the upper saw should have its arbor and girt raised and lowered by screws. The top saw of double mills should be run in the direction opposite to the bottom saw—that is, the tops of the two saws should run in opposite directions—thus making both the upper edge of the lower saw and the lower edge of the upper saw run toward the advancing log. This arrangement brings the cut of both the upper and the lower disc against the grain of the timber, making the saws work more easily and track better, and dulling them less in sandy bark. By hanging the top arbor in advance of the lower there is avoided all danger of a wide board wedging between the standard and the saw. In improved double mills both ends of the upper arbor-hanger are raised and lowered together, and are thus kept parallel with the lower ones. Not only can the double mill saw larger logs than the single mill, but it can also use smaller and thinner saws, which can be run more rapidly and will cut a narrower kerf. These saws are more easily kept in order, are less liable to accident, and cost less to replace. When the lower saw is worn too small, it can be put on the upper arbor. Double mills enable the sawyer to use saws of the right size, and thus to make as few slabs as possible, and therefore they are the best unless all the logs run small. In recent three-high circular mills the arbors are of such length that a 50-inch plank may fall

away from the cut without touching the mill-frame uprights, and thus largely prevent accident to the saws and save the manual labor which would otherwise be necessary to lower wide planks upon the rolls or skids.

The Feed of Circular Saws may be either (1) by hand, upon a table, and generally along a guide; (2) by smooth gripping-rolls, as in the resaw; (3) by rough rolls, which hold the board down to a table while they dig into the wood and force it along; (4) by a spur-wheel, which grips it; or (5) by a carriage. The carriage (1) may have wheels which run upon a smooth track; (2) may run on stationary wheels below it; (3) may be drawn by a rope or a chain; (4) may be propelled by a pinion gearing into a rack upon the carriage; or (5) may be attached to the cross-head of a long-stroke steam-engine, which gives direct feed. Or, if the timber is long, it may be fed along rollers upon a frame; this, however, serves only for stock having practically but one plane side. The material may be fed upon a table supplied with rollers, or may be guided and fed between horizontal rollers for ripping, or by vertical rollers for splitting and for resawing boards. Pressure-rolls for feeding in logs should have a powerful spring, but so flexible that the rolls may yield to a log which is thickest at the tail. Where there is a roll-feed for resawing-machines the two sets of rolls should be self-centring, so as to give equal pressure from both sides, and, no matter what its thickness, to present to the saw the centre of the strip or board. Self-feeding saw-tables should have, in line with the saw, the spur-wheel which draws the lumber, so that the mark of the wheel will be effaced, and the wheel should be slightly "cut around," so that the piece to be ripped will be pressed to the gauge.

The Carriage (1) may be on rollers or wheels, guided by a track, or (2) may have on it rails guided by rollers on the floor. The log or other wood may either rest upon or be held out bodily from its side. The carriages of long mills are best made in sections of from 15 to 16 feet in length, connected by rods and dowels. Having the ways on the carriage and the rolls on the floor prevents the raising of the carriage by bark or sticks and makes it run lighter and easier. It is also less difficult to keep rolls in line and on a level than on a track; they do not obstruct when the mill is being swept or when it is crossed with barrows, etc.; they last longer, because each revolves only as the carriage passes over it, instead of continually, as when on a carriage; they are more readily replaced and are more economical, because those opposite the saw-frame, which are most used, can be moved to the ends. One peculiar form of a power-fed edging-machine (*pl.* 11, *fig.* 7) has a carriage attached to a rope-feed run by friction-gearing and with rollers which run upon ways on the bed.

It is well to have the gig-feed driven from the saw-arbor, so that whatever affects the speed of the saw will in the same proportion vary that of the carriage. The objections to racks and pinions for feed are the annoyance and delay caused by breaks. To make them extra wide and heavy adds too much to the weight of the carriage. Chain-feeds neither slip nor "run bad," as belts often do, and this is in most cases an advantage.

While in some instances belt-slip relieves the machinery and prevents breakage, it is usually better to have "give" in the friction-feed of drive and chain than in the belt. Feed-works should have from three to five different rates of speed, according to the timber, and should run ordinarily from ½ an inch to 3 inches per revolution if there are five changes. It is well to have an extra set of cone-pulleys, to give different rates if desired. For feeding saw-tables a paper friction-feed allows the carriage to be moved fast or slow, and to be stopped and started at any point of travel. Such paper gear should be protected from snow, dirt, and moisture. There should be no friction device which is likely to start the carriage while the logs are being put upon it.

Shot-gun Feed.—For rapid cutting in soft woods there is employed in the Western portion of the United States the "shot-gun" feed, which might be called a direct-acting steam-feed. The device for moving the carriage is a telescopic piston and cylinder of such length as to give a throw longer than the longest log to be sawed. The carriage-head is fastened to the piston-rod, and steam is admitted to the front or to the back of the piston by a three-way cock controlled by the sawyer. The cylinders are from 18 to 80 feet in length, and from 7 to 10 inches in diameter. To advance the carriage and to make the cut the sawyer admits live steam behind the piston, and to return it the valve is so shifted that live steam enters in front of the piston and the back cylinder-end exhausts. The rates of feed and return are almost incredible.

The Accessories of the Carriage are the head-blocks and uprights with their dogs, the feed-works, the gig-back, the set-works, and the log-turner.

Fences and Guides.—For accurate ripping there are needed guides, which must be parallel with the blade. There are also used cut-off guides for insuring that a certain quantity is cut off at one end of every piece; also mitre-gauges, to make all the angles of the mitres the same.

Set-works, or devices for advancing the log by the amount of the thickness of the board before each cut, are composed (1) of the head-blocks with their side-supports or uprights (*pl.* 11, *fig.* 6), to hold the log firmly; (2) of the set-beam or slide, which carries the blocks and advances them all alike if so required; (3) of the setting-mechanism, by which the log and its supports are moved; (4) of the drawback, which brings the set-beam and the slides back after each cut; and (5) of the indicator or scale, which shows at a glance the distance between the saw and the uprights. There are generally three slides, to prevent the log from springing. Set-works usually consist of a shaft turning in bearings and having pinions engaged in racks fastened to the head-block side. Suitably-rigged gearing enables the blocks to be moved toward the saw any desired fraction of an inch. In improved mills the operator, by pressing his foot upon a pedal while gigging back, can raise or set back the uprights any desired amount, the actual work being done by friction devices.

Mill-dogs.—In nearly all head-blocks there is provision for holding the balk or cant by its side at several places in its length. The "mill-dogs"

(*pl.* 11, *fig.* 9), or devices by which the log or cant is firmly held to the head-blocks, are so called because they hold by teeth or tooth-like projections, which bite into the timber, being either driven in by a maul or pressed in by a lever, cam, eccentric, or screw. Frozen logs require specially strong dogs.

Saw Accessories.—The saw and its arbor may have as accessories the devices for giving "lead"—that is, a slight angle between the plane of the saw and the line of motion of the carriage—guides, to keep the disc from swerving, and the spreader or splitter, to keep the board just cut from touching the disc and to lessen friction. Lead is best given by adjusting the bearings of the saw-arbor. The guide should have rapid adjustment for saws of different dimensions, and its jaws should be movable independently of each other and while the saw is in motion and the mill running. The mandrel should have its end play regulated from the middle. The splitter-wheel should not be upon any axis which bears a roll on which the lumber rests. There should be opposite and nearly touching the saw-plate cast-iron bearers or supports, to hold short pieces as they drop from the saw, and to prevent bits of bark, splinters, or slabs from wedging in against the saw. In gigging back on band-saw mills the saw may be deflected automatically or by a foot-lever. The mandrel should have one collar fixed and the other removable; these collars prevent end-wise motion. The saw or plate is held between two flanges, through which and the disc pass two bolts. The boxes of the mandrel should be of great length. To cool the saw or to prevent it from heating, the mandrel is sometimes made hollow, so that a current of water can be passed from one end to the other and ejected through the collar. Sometimes one end of the mandrel of a small machine is arranged to receive an auger-bit.

The Resaw, which is used for dividing thick boards into thinner ones, should be very thin, that it may cut a narrow kerf; for this purpose it is often made segmental, thin rim-segments being screwed to a thick centre-piece and dovetailed to one another. The feed is by vertical rolls, which should be so arranged that if desired they will bring all the pressure to bear upon either side of the board. To prevent the collar from splitting the lumber ahead of the saw, a board of the requisite width, on top of which the lumber may be fed, may be put between the rolls before the saw is ranged, so that only enough of the disc shall be presented to make the cut. Resaw frames are best made with the ends open, so that the plate may be rolled out instead of being lifted.

Cut-off saws may move either the saw and its mandrel or the stock; in the former case the saw may be swung, or it may be on ways. In the latter case its path is usually horizontal, and such machines are commonly called "railway" saws. They may be mounted in a regular frame or may be hung in brackets, as is most convenient. A very useful and popular machine is the carriage cut-off, which has a stationary table at the left of the saw and a travelling carriage at the right, for cutting off. Some cut-off saws are swung in loops, and these are best bored and fitted

carefully upon each end of both the counter-shaft boxes, by which means the cause of wear upon the counter-shaft is removed and the shaft relieved from the weight of the swinging frame.

Circular Edging-machines.—The "edger" is a gang-ripping circular saw for putting clean edges on boards which have been sawed from round cants, and for ripping wide unedged boards into narrow ones. This machine is a potent factor in saw-mill economy. A wide board may have in it two grades, and the edger-operator may by good judgment so divide it as to give two boards (one of high and the other of low grade) worth more than the one wide board. In gang edgers of recent construction (*pl.* 12, *fig.* 2) the saws are moved upon their arbor by hand-wheels at the front end of the table, convenient to the operator, and are so arranged that two saws may be locked together 4, 6, 8, 10, etc., inches apart, and so move together or separately as desired. With the most recent power-feed single-saw edger the operator may send stock past the saw and return it without changing position or leaving his place. Where only wide boards are sawed, edgers should have rolls of the full width of the machine. For narrow stuff the rolls are broken in their length, whereby two boards of different thicknesses can be handled at once without difficulty. An effective edger for straight work should be provided with two sets of live feed-rolls, and also with back feed-rolls. Some not only have their feed-rolls grooved lengthwise, but also have the back roll cut on its periphery, so as to form a kind of teeth, which serve to keep the lumber straight as it goes through, thus avoiding the tendency to follow the grain. In some gang edgers all the rolls are driven, the return roll upon the top having a reverse motion, thereby feeding instead of shoving back the lumber. There is a rack upon the front extension, between the two front rolls, to prevent the boards returned over the top of the machine from getting down under the rolls. In one form of this machine one end of the arbor is carried in a bridge-tree, which may be readily removed, so that all the saws may be slid off.

Shingle-saws.—Shingle-sawing machines usually employ circular saws, which are generally "flat" or on vertical arbors. Some have reciprocating carriages for the "spalt," and others have a rotary motion. Some employ but one saw; others, two or more. The logs are sawed into bolts or lengths required for shingles either by a drag-saw or by "bolters" having two saws, which are set as far apart as the length of the required bolt. The shingle-machine (*fig.* 1) divides the bolts into shingles, the block or bolt being placed on the tilt-table (*A*). The slides (*B*) are so planed into the tilt-table top (*A*) as to allow them to be moved ahead toward the saw as the latter wears up. This table hangs on trunnions and oscillates as the "tilt-lever" (*C*) is moved from side to side. The "butts" and "points" of the shingles are regulated by the four hand-wheels (*D*), which are also used to set the table-top parallel with the track of the machine. The tilt-levers do not have to be moved every time a shingle is cut, but are used to throw knots, etc., when possible, into the point of the shingle, and

also so as not to saw the wrong way of the grain. The spring-lock on the tilt-lever (I) is for holding the lever against the stop, so that it will not rebound. When "heading" is being cut, the stops are turned down, so as to hold the table level. As heading is the same thickness from one end to the other and does not require a tilt-frame shingle-machine, the shingles go to the "jointer," who joints them on the edges (usually on a wheel carrying knives), throwing aside the knotty ones to be slit up later on a knot-saw.

In one variety of flat-saw shingling-machines the ways on which the shingle-block rests can be adjusted to any thickness or any taper by four hand-screws. The first screw changes the shingle to thick or thin, the second regulates the butt, the third controls the top and is held by jam-nuts, and the fourth changes the rake in the saw on the top. On such a machine, if a block is 4 inches thick on one end and 10 inches on the other end, it can be sawed with all the butts on one end and all the tops on the other, thus bringing the block even at each end and making the entire block into shingles, except a thin slab. The saw strikes the block on the side, which operation is considered to make a smoother shingle than by entering the saw at the end.

A new type of shingle-dresser is a planer with an endless wooden carriage having beds, in which the sawed-joint shingles are put and held in place by pressure-rolls held down by springs, so that while being planed they are sprung into a dished board transversely across the shingle-bed. When they come out, each has a convex upper face thinned down at the left edge, so that, in driving, the thick side overlaps the thin edge, and thus the shingles, when on the roof, rest on their two edges, leaving an air-space between. It is claimed for them that as soon as the rain is over they dry at once, while joint shingles, lying flat together, become waterlogged and rot in the lap. A 24-inch shingle of this kind is put 11 inches to the weather, while in a joint it would be only $7\frac{1}{2}$ inches, thus covering more surface, saving one-third in lath, and making, it is claimed, a roof that will last much longer.

The Band- or Ribbon-saw, which is an example of a continuous-acting mulay or jig, is practically a pair of driving-pulleys with a steel belt, one edge of which has cutting-teeth. It may be considered a development of the endless knife used in cutting cloth, the microscopically fine teeth of the band-knife being magnified in the band-saw just as the cold-sawing disc for cutting iron merges into the toothed circular saw for the same purpose. In band-saw machines there can be but little variety except that which is purely structural. In every form there must be a driving-wheel and a driven wheel, the saw-blade being the belt. Provision must be made for a constant yet adjustable band-tension, and there must also be a coarse adjustment for taking up the blade as it is shortened by breakage and mending. In all there must be either (1) a carriage permitting the stock to be fed in one direction without swerving, or (2) a table upon which the material may be either fed against a guide or moved in the horizontal plane, to

permit of cutting curves built up of very short straight lines. All require for the blade some guide to keep it from running out of line; all demand that the wheels shall have a friction surface that will lose as little as possible by slip caused by the very unfavorable material constituting the belt; all should have provision for suddenly stopping the driving-wheel. Some have an arrangement by which the tire of the driven wheel may slip around upon its felloe, so that when the driving-wheel is suddenly braked the driven wheel may keep on revolving, but the blade may stop.

Band-saws are used to cut both straight and curved lines, and are employed on the most delicate fret-work and also on the heaviest log service. They are either hand-fed or power-fed. The wheels of those for fret-work are from 30 to 72 inches in diameter; of those for logs, from 72 to 96 inches. The saws for fret-work are as narrow as 1/8 of an inch; those for log-work, as wide as 8 inches. The great advantage of the band-saw is the thin kerf it makes, which saves both lumber and power. As compared with an equally good circular saw, a good band-saw will save a fifth of the material in working a choice lot of logs. Moreover, the lumber produced by the band-saw is better and smoother and can be dressed with less waste than that turned out by the circular saw. As the band-saw makes its cut at right angles to the grain, it has an advantage over the circular saw, which cuts largely parallel with the grain. The smaller the disc, the greater its disadvantage; furthermore, a circular saw is liable to scour the log with its rear edge, thereby reducing the quality of the lumber. For places where it would be difficult to put a band-saw with the ordinary large frame, and for a class of work where a large saw is not needed, as in ordinary pattern-work, there is provided a machine (*pl.* 12, *fig.* 7) which can be attached to any ordinary post or wall-plate.

Combined Scroll- and Resaw-machines.—In shops where there is some resawing and considerable scroll-sawing, but where for want of room a large special resaw would not be advisable, a combined scroll and resawing band-machine may be applied, the frame being that of the ordinary band-sawing machine, to which there is a resawing attachment, consisting in one type of six rolls, of which four are geared together, the two smallest next the saw and acting as guides. These rolls are driven by a friction-wheel and disc, which vary the feed from 5 to 8 feet per minute. One convenient form of band-resaw (*fig.* 5) has the table in two parts, divided at right angles to the saw-teeth. The front portion, which bears the feed-rolls, may be thrown down and under, feed-works and all, to make out of the machine a plain band-saw. In one type of combined band-scroll and resaw (*fig.* 6) the column is cored, and has in it an opening for the passage of the lumber. This permits the placing of the feed-works in such position that it is never necessary to disturb the rolls when the machine is changed from a resaw to scroll-work. The scroll-sawing, which takes the least thickness of cut, is done upon that side which brings the work farthest from the standard, the resawing being done in line with the stand-

ard itself. Of course it is necessary to reverse the motion of the blade for resawing, so that each kind of work shall be done with a down-running edge. This is accomplished by placing upon the counter-shaft one tight and two loose pulleys, using a straight and a crossed belt and changing saws. In changing from one kind of work to another it is only necessary to change saws and to use the proper belt, and the machine is ready for work.

The Duplex Band-sawing Machine, which was suggested by the writer about 1878, has since been carried out in one in which the wheels of one band have their axes parallel with those of the other, all four wheels lying practically in the same plane, their rims being as far apart as the width desired to be left between the kerfs; the bands running in opposite directions, so as to bring both down-running sides together. One pair of wheels has the ordinary C-shaped frame, and the other, the movable one, has a straight column, the distance being regulated by a screw and hand-wheel, which move the column-frame along the sole-plate joining the two sections. This machine is especially adapted for sawing rims and felloes, the C-shaped frame having a suitable guiding arrangement for the curved cut necessary. The cored-box section of band-saw frame has driven out the I-section, being stronger and more sightly. For many kinds of fine work the band has entirely superseded both the "mulay" or free-ended and the strained jig-saw, except, of course, for inside work, for which it is unavailable. It is also largely used for resawing and for log-sawing.

Stone-cutting Saws.—Saws driven by machinery are also used for cutting stone. Instead of steel, the blade, which is toothless, is of soft iron, and the cutting action is obtained by a constant current of water and hard angular sand or emery. The grains of sand, getting under the blade and being carried along for some distance, scrape off the opposed particles of stone, while the current of water constantly removes the resulting sludge. Such a stone-sawing machine is shown in Figure 3 (*pl.* 12). The ends of the blade are fastened in two jaws, which are connected by a belt running over two guide-pulleys and are given reciprocating motion from a revolving driving-shaft. The boxes of the guide-pulleys are on vertical slides, which can be moved up and down by two racks and a pinion, the block of stone being firmly held while carried toward the saw. By substituting for the toothless iron blade a steel blade with suitable teeth this arrangement can also be used for cross-sawing logs, which the draughtsman has intended to indicate in the illustration by the manner of hatching. (R. G.)

II. MACHINES FOR MANIPULATING FINISHED OR PARTLY-FINISHED MATERIALS.

I. WOOD-WORKING MACHINES.

In wood-working machinery there are ten principal classes of operations: (1) Chopping, riving or splitting; (2) sawing; (3) planing or shaving; (4) incising; (5) boring; (6) routing; (7) turning; (8) bending; (9) polishing, and (10) compressing.

Chopping and Riving or Splitting are very simple operations, effected with primitive tools, and generally without the aid of machinery, although in making kindling wood and square-sectioned match-splints, power-driven splitting-machines are used. The axe, the hatchet, and the rail-splitter's wedge are familiar to all and need no illustration. Their work may produce chips or it may produce no waste as in ordinary splitting.

Sawing is referred to in great fulness of detail, under the head of Saws (p. 65, *et seq.*); and saws are employed in tenoning-machines, referred to later on (p. 86). The waste resulting from the use of saws is in the form of saw-dust, small chips, or saw-dust and blocks.

Planing and Shaving Tools and Machines, with which may be included those for moulding and those for "matching" (or tonguing and grooving), pare or slice off the material from the surface, usually working lengthwise of the grain, commencing at one end of a piece and working toward the other. The waste from their work is in the form of long shavings or of short shaving-like chips. Hand-planes, spoke-shaves, and planing and matching machines are employed here. The paring-chisel and the gouge, also used in such actions, work lengthwise of the material and remove shavings and chips, the chisel having its cutting edge straight and the gouge curved. Hand-planes are shown in Figures 2 to 13 (*pl.* 13); a spoke-shave in Figure 28; paring-chisels in Figures 29 and 30, and gouges in Figures 31 and 32. Planing, moulding, and matching machines receive full attention later on. The plane is a tool for working the surfaces of solid bodies by being carried over them to and fro with straight strokes. In hand-planes the edge is prevented from penetrating too deeply into the surface of the material to be worked upon by being contained in a fastening or "stock," which limits its protrusion. In planing-machines the rectilinear motion of the piece to be planed or that of the tool is secured by special guides. The application of the hand-plane is limited to soft materials (wood, soft metals), while for planing hard materials (as iron) power-driven machines are generally used.

Wood Hand-planes.—Figures 2 to 13 show the form and arrangement of the most important hand-planes. They have either single "irons" or bits (*figs.* 2, 3, 5) or double bits (*fig.* 4). Upon the front of the cutting-bit in Figure 4, the edge of which detaches the shaving, lies a shiftable top-iron or breaker, whose lower edge is set close to the edge of the cutting-bit. The shaving, ascending before the bit, is partially broken

by this breaker, thus preventing "tearing" in case the fibres should run unfavorably. For this reason planes with double irons (*pl.* 13, *fig.* 7) are especially suitable for finishing surfaces. Figure 2 shows the bit of a jack-plane which serves for roughing. The edge of the iron is convex, so that the resulting shavings will be thickest in the middle of their width. Figure 3 shows the bit of a smoothing-plane, which is distinguished by a straight edge. Figure 5 represents the bit of a plough (grooving-plane), in which the edge corresponds to the profile of any moulding. The iron is secured by a wooden wedge driven tightly in front of the plane-iron or forced in by a screw or lever. In the ordinary planes (*figs.* 6–8) for working surfaces free all around, the edge of the iron does not extend the entire width of the stock, which renders it impossible to continue the smoothing to the innermost edge of a re-entrant angle; to do this the plane-stock is given the form shown in Figure 9 (rebate plane), and the lower portion of the bit may have a slightly greater width than that of the stock. For smoothing a surface bounded all around by a plane ascending at a right angle—for example, a mortise—a router-plane (*fig.* 10) is used. In this form the iron stands free all around, the peculiarly shaped stock being guided upon a surface parallel to that to be smoothed. For smoothing the sides of a mortise with rectangular cross-section the bit as well as the cross-section of stock receives a T-shape, the plane being known as a T-rebate (or rabbit) plane (*fig.* 12). The planes shown in Figures 11 and 13 serve for grooving level and concave surfaces. In the stock are two scoring-cutters, which precede the plane-iron and cut the fibres to be detached by the latter.

The bench shown at Figure 1 serves to secure the piece to be smoothed. To a thick hard-wood slab are fixed two parallel-jawed wooden vises, one or the other of which is used as needed.

Planing-machines.—Machines for planing or smoothing "timber," as the English call it, or "lumber," as the Americans term it, work principally with rotating cutters, although some employ stationary blades like plane-bits, as shown in Figure 34, where three such bits are used. Rotating cutters generally have their axes parallel to the plane of the surface to be produced, and of these some use straight and others spiral blades. Most of those using straight blades are set at right angles to the direction of the feed, though some are set diagonally. Those using straight blades and having the axis of the cutting-cylinder at right angles to the bed usually have the blades so set as to cut with the entire length of each at once, though some have the blades so set as to produce a shearing cut, thereby simulating the action of spiral blades.

Where there is desired greater accuracy of surface than can be produced by rotating cutting-blades parallel with their arbor, spiral blades are sometimes used, although they are not very generally known. They are sharpened by means of a broad-faced emery-wheel, the blades and their arbor being mounted in rigid bearings, and the wheel having, in addition to its rotation, a traverse motion exactly parallel to the axis of the cutter-

shaft journals. The spiral-bladed heads have the twist run from one end toward the other, not from the centre both ways, and the cylinder is placed at right angles to the passage of the material. Rotating cutters, which have their axes vertical and at right angles to the surface to be produced, have as cutters bits which are set either in the face of a disc or at the ends of opposite arms at right angles to the axis of the head. Although most wood-planing machines have their cutting-cylinders at right angles to the feed, some have diagonal cylinders, as in Figure 1 (*pl.* 14). Some single-cylinder machines plane the under surface of the stock, working it parallel to the bed; others pass it under the cylinder and work its upper face; and yet other machines may be arranged in either way.

The Dimension Planer has a rotating cylinder which carries two or more knives, either straight or spiral, and the material is fed under this cylinder upon a travelling table. This works but one side at a time, and is generally used for large timbers. It is often arranged to feed and cut in either direction. In one form of this machine, known as the Daniels planer, there is a vertical shaft bearing a horizontal arm at each end of which there is a cutter. As the shaft rotates rapidly the work is fed along under the cutter-arms. Some machines for the same purpose feed the material in upon rollers; others have an endless apron. In the Daniels planer the table or bed may be made in lengthwise sections bolted together, so as to give any desired length with the fewest patterns.

In some types the stock can be run diagonally under the cylinder instead of setting the cylinder in a diagonal position, which has the disadvantage of not permitting straight belts to be run to the cylinder. Running the stock in diagonally, however, permits feeding in short stuff. A matcher-head which does good work has four sides, as in an ordinary cylinder-head, but each is fitted with a bit milled out on both sides, thereby throwing the cutting-edge to the centre of the bit, with the object of preserving the cutting-edge as long as possible. The heads are of gun-metal and the slots for the bits are milled in and dovetailed, the bits being held in place by steel studs.

The Stationary-bit Wood-planing Machine (*pl.* 13, *fig.* 34) has three plane-irons, in working which the lower side of a board runs over the edges of three plane-irons, each of which detaches a broad shaving, while the upper side of the board rests against stationary rolls. The bits extend the entire width of the board, this being permissible on account of the softness of the material. The board is fed forward by the motion of smooth or fluted cast-iron rolls arranged in pairs front and back of the bits. Machines of this kind are used for smoothing boards and posts as well as for cutting very thin boards for the manufacture of boxes, etc. Steaming the wood renders it extremely soft and permits giving great width to the bits, so that such a machine can be advantageously substituted for a veneer-saw, there being no loss from sawdust. In some very large machines for rough work upon frozen pine and the like the machine has several stationary plane irons, which take off rough cuts before the rotating cutters strike

them. One Norwegian machine takes from twelve to fourteen successive cuts from a board at one pass. The machine shown in Figure 34 (*pl.* 13) has also revolving cutters for working the edges of the boards.

Planing- and Matching-machines.—The use of rotating cutter-heads for planing one side of a piece of timber having been soon followed by the smoothing of two parallel sides at the same passage, it was not long before side-cutters were devised for smoothing or for matching one or two edges at the same pass. In working all four sides at once planing cutter-heads may be used in connection with matcher-heads, so as to form and finish at once all four sides of a board; four planers may be employed together, to square and finish all four sides of a joist or sill; or one or more moulding cutters may be used in connection with simple planing cutters. In many surfacing- and matching-machines the matcher-hangers are attached to a vertical adjustable frame, which, with the heads remaining upon the spindles, may be lowered under the line of the cylinder-bed. Matcher-heads which move up and down with the bed save trouble and expense in separate adjustment. A desirable feature in matching-machines consists in having both the matcher-spindles and guides movable across the machines with one crank, so that the bed can be worn equally across its whole surface.

The Vertical-feed Matching-machine shown in Figure 2 (*pl.* 14) is for tonguing and grooving short stuff. The two heads—one for tonguing and the other for grooving—are run on a steel arbor under the table, which latter is planed to take up the cut as the work passes over the cutters. One of these cutter-heads works upon each side of the fence, which is rigid and has two idler rollers, to relieve it from friction. There are two feeding-rolls.

Feed of Wood-planing Machines.—The feed of wood-planing machines may be (1) by hand over a plane bed; (2) by a travelling solid table, as in the Daniels machine; (3) by the Woodworth method of setting at right angles to the table of the machine friction-rollers, which draw the stock to the cutters; or (4) by a travelling bed like an endless apron. Some machines have two, and even three, of these means of feeding. The Woodworth type has a horizontal rotating cylinder, as in the ordinary dimension planer, but the feed is by pressure-rolls. Some machines have a combination of the Daniels and the Woodworth methods—that is, they have pressure-rolls for holding the work down to the platen in working by the Daniels system, and feed-rolls for planing "out of wind" or to a true plane. When not in use, the feed-rolls are moved back out of the way on slides. When used for surface-planing, the table is placed with its end under the cylinder and pressure-rollers, the feed-rollers being then moved into position. The platen or carriage has friction feed-works with change of speed, and the machine is so arranged as to plane while the carriage is running in either direction. Feed-rolls are either "live" or "dead," live rolls being geared so as to have positive motion, and dead ones being merely guides. For feeding in two boards of unequal thicknesses side by side

under a cutting-cylinder the upper feed-rolls may be divided in the middle, so that each end may work independently. Having swivelling-boxes for the feeding-in rolls allows them to accommodate boards of uneven thicknesses and to give equal pressure to each side of a board without undue strain on gearing and screws. It is desirable to have a pair of feeding-out rolls for most planers; otherwise, where the last piece is spoiled it may be difficult to get it out of the machine. In double-cylinder planing-machines where side-matching is done there are three pairs of feed-rolls, two pairs before the cylinders and another after the matchers, carrying the lumber entirely through the machine and keeping it all the time in a straight line.

In an excellent smoothing-planer (*pl.* 14, *fig.* 7) there are four driven feed-rolls connected by a train of expansion gears. The two lower rolls rise and fall with the bed and the upper ones are held in position by weights. The table is supported upon long inclines and raised and lowered by a screw and a hand-wheel. In some machines all bearings connecting the feed-works are provided with ball-and-socket self-adjusting boxes.

For heavy surface-planing the machines are best belted at both ends. In some excellent makes the feeding-in roll has weighted pressure and the feeding-out roll has a spring, the latter roll being encased, to protect it from dust and shavings (*pl.* 15, *fig.* 5). There are on each side of the cylinder self-acting pressure-bars, the one in front rising and falling with the feeding-in roller and always retaining the same relative position, yet yielding to any inequalities in the surface of the material. The bed has friction-rolls at its ends and is raised and lowered in gibbed ways, to suit different thicknesses of lumber.

One method of weighting delivery-rolls (*fig.* 2) for matching-machines throws the weight across the machine, the levers being connected, so that the leverage is more uniform and the pressure is sufficient to carry out the board without any additional weight, although the pressure-bar upon the upper cylinder is kept in proper place. There is a weighted pressure-bar before the cut and also a pressure-roller with springs, the tension of which may be controlled by a screw and a hand-wheel. The cylinder-frame, which carries the cutter, is gibbed to the sides, and the cylinder and pressure-bar adjust together to the thickness of the cut. In some of the best surface-planers the cylinder and feed-rolls raise and lower together, to suit the convenience of the material to be planed, always retaining, however, their relative position with respect to the bed-plate. Besides the friction-rolls both before and behind the cylinder, the table itself has friction-rolls at each end.

Combination power- and hand-feed surface-planers (*fig.* 7), which are desirable in shops having a wide range of work, may be arranged to plane under the cylinder by feed-rollers, or the bonnet and pressure-bar may be removed and the end table raised to the proper height by a screw and a hand-wheel, so that planing may be done by hand-feeding over the cylin-

der. As arranged for hand-planing the platens cover the cylinder and feed-rolls, and no obstruction is presented.

Endless-bed Wood-planers.—The advantage of the endless-bed planer is that it can feed lumber into the machine under more varying conditions than a roll-machine. It will take in and properly handle, if of suitable design and construction, lumber that is hard or soft, green or dry, wet or icy. It will work warped or icy material which no other planer will carry in. It is usully built with but one cutting-cylinder, although sometimes with two or more, or it may be provided with Daniels cutters. Some endless-bed machines raise the bed, others the cutter-head. Moving the head is a convenience, particularly when necessary to plane long heavy stuff. In very large machines (*pl.* 15, *fig.* 1) the cylinder is stationary, which makes it permissible to have the counter-shaft either on the floor or overhead.

One objection to the ordinary endless-bed machines is that there are two shoes for the travelling bed to pass over, leaving between them a space of 10 or 15 inches, and thus giving the lags no support between the shoes. The lags also are apt to cut and indent the worked lumber, and to gather gum and fine dust upon their surfaces, causing irregularity in the lumber being planed; or a knot or a chip will carry around on the bed and raise the lags into the knives. To overcome the trouble of the unsupported bed end one maker constructs the bed of a series of ribs placed diagonally across the whole width of the machine (*figs.* 3, 4), thus supporting the lag its entire length. This secures uniformity of lag wear and gives a weight of iron to serve as an anvil for the blow of the knives; it also prevents accumulations of dirt or gum upon the lags. The bed is lubricated by a roll covered with sheepskin with the wool on, and in such position that it revolves with the travelling bed. From it runs a perforated pipe connected with an oil-pocket.

To enable two or more pieces of different thicknesses to be planed at once on an endless-bed machine, instead of having a "broken" roll—that is, one broken in its length and having a centre-bearing, which must of necessity be small—the rolls may be hung on an eccentric shaft made out of a steel forging. The rolls revolve upon the shaft, which swings in boxes at each end. The shaft, turning in the box, accommodates itself to any irregularity or thickness in the lumber.

The Double-cylinder Endless-bed Surfacer (*figs.* 8, 9) has the line of the bed fixed, the upper cylinder and the pressure-bar over the lower cylinder-bars adjusting together to the thickness of the lumber. Both the bar and the lower cylinders may be raised or lowered while running. The rolls and pressure-bars are divided, so that one wide board or two boards of unequal thickness may be worked. For dressing on all sides large car-sills and timber an excellent machine (*pl.* 16, *fig.* 1) has its bed fixed to the cylinders, and adjustable rolls to suit the various thicknesses of material. There is an endless-bed feed, besides which there is a pair of large feeding-rolls expansively geared, to draw the material from the side

cutters. The material is worked first upon its upper face, then upon its sides, and finally upon the lower surface.

Endless-bed Dimension-planer and Jointer.—Figure 8 (*pl.* 14) illustrates a very useful machine which combines the features of an endless-bed dimension-planer and a jointing-machine, and which will finish on three sides and work two pieces at once. The feed is of the endless-bed type; the upper cylinder is in a raising-frame, the lower cylinder is in the main frame, and there are two side-heads, which move across the machine. The side-heads are removable from their spindles, to permit of wide surfacing, and their frames are separately adjustable across the machine by a long screw attached to each. The pressure-bar, which presses on the work after the cut of the upper cylinder, is adjustable, and that over the lower cylinder is adjustable vertically, independently of its being raised in connection with the upper cylinder. The bed is always in one position. Over the travelling bed are two independent or broken rollers, under which two boards of unequal thickness may be placed and by which they may be fed in at the same time. There are two independent pressure-bars before the cut of the upper cylinder and a pressure-roller after its cut, to retain the boards in position after passing the cylinder.

Blind-slat Planer.—An important machine in blind manufacture is shown in Figure 4. It is designed to dress with the grain all four sides of a slat, thus saving a large proportion of the rough slats made where one side is dressed in the opposite direction. There are two tables, one lower than the other; the material is fed over the lower one and under a cutter-head that dresses one side, and as it leaves the cutter-head the operator reverses it endwise and passes it under the feed-rolls above the upper table, when it is carried to cutter-heads that finish it on the opposite side and edges.

Cutters for Moulding and Matching.—The days of working out mouldings and of matching flooring by hand-tools operated like planes have gone by; instead of sliding a cutting-tool along stationary work the stock is fed along, to be worked by rotating cutters, which give the proper profile. By this, speed is multiplied almost beyond computation and the quality and the accuracy of the work are greatly increased. A good machine is of very little use unless it is supplied with proper cutting-bits, and these are useless if difficult to sharpen and keep in order or if likely to lose the size or profile corresponding to the surface which they are intended to produce. This is particularly true with matcher-heads for wood-work. In this respect a very important step has been made in the circular bit-head (*fig.* 3). Each bit is ring-shaped and carries the outlines of the pattern which it is to cut. The entire outer circle is tool cutting-edge. The bits are fastened to the rotating head by bolts and nuts, making a strong and durable tool which has weight "low down" and in the line of the cut. For matching, these heads are arranged in two series, consisting of upper and lower bits, that divide the chip upon a central line of cut. First one bit makes a cut, to be followed by the next one of the other series; therefore the entire

cut is not made by one stroke, but by first one and then the other series, to complete the full outline of the shape to be produced. This division of cut demands special adjustment of the bits, giving them side clearance, the same as a new tooth when set, by securing them to their respective seats in the slanted position, so that no part of the bit but the cutting-edge shall come into contact with the lumber.

With the latest improvement the heads carry the bits that belong to the several series on opposite sides of a central flange, thus adapting the head to any expansion or change of tongue or groove. As the bits are worn down by work and sharpening they are turned around on their seats until worn down to the safety-point, which does not leave much of the material. To make the tongue and groove tight or loose, the tongue- and groove-cutters are furnished with washers open on one side, and the bits are loosened up, to slip them under. To set the cutters there are employed gauges fitted to their slanted edges, showing the angle at which to file them in order to keep the head to full size.

A very good cutter (*pl.* 14, *figs.* 5, 6) has a cutting-edge formed by milling into the face of the steel instead of cutting the desired shape of the moulding on the edge and then grinding it to a bevel, which latter method makes the form of the cutter liable to be changed in grinding. Where the form of the moulding is worked in the face of the cutter the bit is sharpened by simply grinding the edge to the standard bevel of the bit. These cutters are placed on the head with the ground angle toward the direction of rotation of the head, thus making the cut of the bit come at right angles to the surface, giving a scraping cut and leaving a perfect surface for finishing. These cutters are more readily set than those of the old style.

Tenoning-machines.—Tenons may be produced (1) by saws, (2) by rotating cutters, or (3) by both. When produced by saws (p. 71), the material may be removed as a block, no stock being destroyed except that from the saw-kerfs; or the saws may be set wobbling, so as both to remove and to disintegrate the material. Where rotating cutters are used they may have their axes parallel to the length of the tenon (in which case, even for a single tenon, two separate cuts must be taken by as many heads or the end of the stick must be passed twice over the cutter), or the cutters may have their axes at right angles to the length of the stick, cutting a single, double, or triple tenon by employing two, three, or four sets of cutters in the same head, with a space left between for the tongue or tongues. Saws have the advantage over cutters of taking less power on large-sized tenons, but as their work is rougher, the cutters are more used. Most ordinary matching-machines will do tenoning as one part of their regular work, but there are many tenoners which do little, if anything, else.

Machines for tenoning heavy spokes have two cutters, the upper with a vertical adjustment, to regulate the thickness of the tenon. The lower head is stationary, the table adjusting to regulate the depth of the cut on the under side. There is provision for cutting shoulders of unequal lengths and for their accurate separate adjustment. The spoke is held in

a carriage, which travels in a horizontal plane, being attached to a vibrating lever pivoted below. For making blind-slat tenons in large quantities there is employed an automatic blind-slat tenoning-machine which feeds the stuff (of any length desired) endwise through radiating chucks, the shoulder being pressed against an adjustable gauge for regulating the slat length. The cutting-tools make two tenons at once and cut off the piece with one cutter-head. The slat is rotated, so as to make a more perfectly cylindrical tenon. To avoid splintering or tearing, the cut is from the outside toward the centre.

Car-sill Tenoning-machine.—For cutting car-sill tenons it is desirable to complete each timber without reversal, and for such work a double-platen machine has been produced (*pl.* 16, *fig.* 3), which will cut single, double, or triple tenons on both ends of a long timber, from one face, without turning it end for end. This is done by moving the stick into the proper position on the first platen, securing it, and traversing the heads down by the hand-lever, thus finishing the tenons on the first end; next moving the timber forward on to the other platen, past the heads, until the opposite end is in position, and then traversing up the heads, thus cutting the tenons on the other end and leaving the heads in position for traversing down for the first end of the next sill. In this machine no side cutters are necessary for making double, or even triple, tenons; the heads, instead of the work, traverse, and the cutter-head arbors are at right angles to the length of the stick and parallel to its width, while in most machines there are used for single tenons two cutters parallel with each other and with the length of the stick, as in Figure 2, there being necessary for double-tenoning with these a third cutter, having its spindle at right angles to the other two and to the length of the stick.

The "Gap" Tenoning-machine is so called because of its frame, which is of the goose-neck type and has a deep gap formed across the column, for the passage of the timbers end-wise between the cutter-heads. The sole-plate or bed is similarly "gapped."

Wheel-tenoning work is referred to under wheel-making machinery.

Incising is done by chisels and gouges used in the hand (usually with the aid of a mallet) or in mortising-machines (which both incise and bore). Their cut is generally crosswise of the grain, and chips are the resultant waste. Figures 29 and 30 (*pl.* 13) show hand-chisels; Figures 31 and 32, gouges; and Figures 6 and 7 (*pl.* 16), mortising-chisels for machines.

Mortising-machines.—The days of hand-made mortises are nearly gone, for two reasons: first, there are fewer men competent to do the work properly by hand; secondly, machines are made which do better work at far less cost and in a small fraction of the time. It might be added that mortised construction is less common than formerly, because (1) so many wooden houses are made with "balloon frames;" (2) bent wood is used for chairs and in car-, carriage-, and wagon-work; and (3) straight sticks fitting in sockets are largely used in freight-car construction.

In one class of mortising-machines the chisel-bar has a positive con-

tinuous movement and the work is raised and lowered to the chisel to receive its action. These are simple, fast-running, and well adapted to light work. In a second class the mortise is formed by a revolving traversing auger or bit, which cuts on the side as well as on the end. In a third class the bar carries a hollow chisel and auger, which has a progressive forward movement to the regular depth of mortise, the action of the auger preceding that of the chisel and making a mortise its full size at each forward stroke. This class works best in heavy timber. A fourth class has a graduated stroke, starting from a still point, and increased by lengthening the connection from the eccentric or other driving device to the chisel-bar. This graduated chisel-bar movement is generally effected by having between the connecting-rod, which is attached to the driving crank-pin, and the top of the chisel-bar (which latter has only a reciprocating movement) a double link one-half of whose lower end is attached to the chisel-bar and the other, directly in the same central line with the wrist-pin, to a lever, which permits of throwing it out of line with the bar. When it and the chisel-bar are in the same straight line, the latter has a maximum stroke, but by practically bending the chisel-bar at the top this stroke may be reduced to nothing.

Foot-mortisers work upon still another plan, the work being held and the chisel brought down by a treadle and suitable levers to any required depth. In the best makes this leverage is such as to form a knuckle-joint, thus giving greater power as the tool gets into the work. The tool is brought back by a spring. In all machines having a reciprocating chisel the tool should reverse automatically while the machine is in motion. The bed carrying the work should swing to any desired angle about an axis at right angles to the length of the piece and to the stroke of the chisel. In mortising-machines of the best form the bed is provided with both power- and hand-feed.

Radial Mortising in Hubs.—For mortising in hubs it is advisable to attach to the carriage or bed some chucking device with a properly graduated index-plate by which the spacing may be made accurate and the cut radial. In such cases the variable-stroke chisel-bar is used. A hub-mortising machine of high-grade construction has double chisels (*pl.* 16, *fig.* 5). The table carrying the standards which support the hub is operated by gearing; the hubs are held in a three-jawed universal chuck operated by a single screw in connection with accurately spaced dials. All gigging, spacing, and feeding are automatic.

Hollow Chisel.—Excellent mortising is done by what is known as a "hollow chisel," its cutting portion having four sides, with bevels upon the inside edges and a slight concavity upon each (*fig.* 6). Inside these runs an auger-bit. In working with this the auger is run out of the hollow chisel and makes a round hole as nearly as possible the size of the square one which it is desired to make; it is then withdrawn and the chisel run forward, cutting the square corners and leaving a perfectly square mortise. To make a rectangular hole other than square more than one stroke

can be made; thus a hole 2 inches by 1 inch can be made by two strokes of a 1-inch chisel, a hole 3 inches by 1 inch with three strokes of the same chisel, and so on.

While most mortising is done by chisels, there are certain grades which require the removal of so much material that a rotating cutter is used. Of course most "end" or "open" mortises may be made by a cutter, in the same way as a tenon; in fact, the cut made after changing a single thick tenon into a double thin one is practically end-mortising. Mortising-chisels may be either solid, as in Figure 7 (*pl.* 16), or made with stocks and separate chisels, as in Figure 6, these last permitting the use of a shorter and stiffer chisel.

Boring is done by gimlets and augers, the first worked by hand only and the latter used both by hand and in machines. Figures 20, 22, 23, and 24 (*pl.* 13) show gimlets, and Figures 25 to 27 augers. Twist drills used for wood are of the same general appearance as those for metal (*pl.* 24, *fig.* 10), and differ from augers principally in the cutting-edges of their ends.

Wood-drills.—In drills for wood the cutting-edges are ground at an angle of from 20° to 30°, and in those for metal at an angle of from 50° to 60°. The harder the material to be drilled, the nearer must the angle of the cutting-edges approach 90°. Of drills for wood the ordinary gimlet (*pl.* 13, *figs.* 20, 22–24) is the simplest form. Upon a slender cone a spiral furrow runs toward the left from the point to the top, the edges of the furrow being generally so little sharpened that actual detachment of the material is not effected, but simply a partial forcing apart of the fibres, which, however, suffices to allow the screw to be driven with greater facility. Hand rotation of this simple form of drill is effected by a cross-handle placed on the upper end. The screw-auger (*figs.* 21, 25, 27), besides being larger than the gimlet, differs from it in the sharper angle to which the helical cutting-edge is ground, which therefore allows detachment of broad shavings. The handle requires the use of both hands, while also admitting of greater pressure.

Figure 18 shows a centre-bit. Besides the guide-point, which precedes the process of boring, there is on one side of the broad lancet-shaped end of the bit a cutter with a sharp edge set toward the periphery, and on the other side a radial cutting-edge. The point secures the position of the rotating axis, while the lance-like cutter neatly separates around the circumference of the hole the fibres of wood to be removed, and the radial cutting-edge continuously lifts out these fibres by a helical cut. The bung-hole borer (*fig.* 19) is a modification of this. On one end of a truncated cone are the point, cutter, and lance, by which a hole can be cut in the bottom of a filled barrel for the purpose of inserting a faucet without the escape of the liquid. As soon as the bit penetrates, the hole is closed by the cone, and then the tool is quickly exchanged for the faucet.

Wood-drill Braces.—For better handling the centre-bit there is generally used a brace (*figs.* 14–17). The bit is placed in its lower end, and

the requisite pressure is exerted upon the disc-like upper end with the left hand or with the breast, while the right hand, grasping the crank-handle in the middle, moves in a circle.

Wood-boring Machines are made in great variety of designs. The simplest are plain boring-arbors with only a pulley and frame, and a stop to regulate the depth of hole.

Radial chair-boring machines have two spindles working at the same time and arranged to be set at different distances. The work is fed in on a table sliding on ways parallel to the bits. Some machines have adjustable table and fence and quick-return spindles. Some have more than two spindles, and in some of these the distance between spindles may be regulated with but little trouble; in some, too, the angle at which the bits will bore is adjustable.

In vertical-spindle machines the spindle may be very readily counterbalanced, so that the work need not be moved to the bit, but merely placed in position. The vertical universal borer has a table with vertical adjustment, and also angular adjustment in a plane including the spindle-axis. A three-spindle vertical auger machine has for each spindle separate adjustment across the stick, and for each one, also, its own counterbalance and handle. The table has a series of geared rollers, arranged to run in either direction, moving the timber end-wise either way. One belt from the counter-shaft carries power to all three spindles.

Some makes of horizontal machines have vertical adjustment for the table, which may also be tilted at any angle to the auger-spindle, to permit of boring at any desired upward or downward angle. The boring-spindle is thrust forward by a counterbalanced treadle. For very large work in hard wood the spindle is moved by a screw and a hand-wheel. The gang boring-machine makes a large number of holes at one operation without the necessity of laying them out. The boring-spindles run in frames gibbed to a connection gateway and vertically adjusted by a screw to each. In one type there lies under the frame and at right angles to all the spindles a long drum, and a continuous belt runs on this and on all the spindle-pulleys, the last belt-fold running the length of the machine between two pulleys having axes parallel to those of the spindles. This does away with the necessity of an idler for every spindle. The radial car-borer has a horizontal auger in a frame having motion in a horizontal circular arc of 90°. The bit has lengthwise movement and the table vertical adjustment. One form of horizontal car-boring machine has a horizontal auger-spindle running in a frame at right angles to the column which carries it, but parallel with the face of the column. This bit is mounted in a frame, which has considerable vertical adjustment upon the face of the column. It also has horizontal lengthwise traverse. The sill or other piece to be bored runs upon a number of friction-rolls, which have their axes parallel to the axis of the spindle. The spindle and its frame are raised and lowered by power. The same machine, with an arrangement by which the boring-apparatus may be pivoted to a plate which

allows it to swing to any desired angle in either direction, makes a radial horizontal car-boring machine. For car-work a three-spindle horizontal-auger machine is very useful, each spindle having its own vertical adjustment by power, so that each one may bear a different-sized auger from the others and any one may be used as desired. The table has rollers for the timber, and also a fluted roller and hand-wheel for moving the stock quickly to a determined point. Each bit is brought forward by its own handle when desired.

Multiple Drilling-machines.—To increase to the utmost extent the capacity of a drilling-machine it is frequently fitted with several drills and spindles, which can be worked at the same time. In the small horizontal four-spindle drilling-machine, represented in Figure 18 (*pl.* 24), the rotation is imparted to the articles only, while the drills are fed on in a rectilinear direction; hence this machine may be considered a lathe with four spindles. In either case it represents an important principle for applied mechanics—namely, that of *the multiplication of the tool*, whereby the total expense for frame, moving apparatus, etc., for each separate tool can be considerably decreased.

Combination Wood-working Machines.—In small shops where a great variety of work is required, while the quantity is not sufficient to warrant one machine for each operation, machines are built which can be rapidly and effectually changed from one class of work to another. Putting boring-bits and matching-heads on the end of saw-arbors, changing planing-heads to moulding-bits, and the like class of substitutions, constitute one grade of possible variations in work; but some machines permit of two different operations being performed on opposite sides at the same time, each side working independently.

The American Wood-worker, corresponding with what the English call a "general joiner," is a machine which can be used by hand. In this the material is passed over a revolving cutter-head, the latter working between two tables, each having proper vertical adjustment to suit the depth of cut, and each being on a level with the finished and unfinished surface of the material worked, the arbor and bearings being so arranged that heads for various work can be put in. What are known in America as "variety wood-workers" have a heavy arbor running in long bearings; the rear one, with the arbor, is arranged to move end-wise, so as to give greater accuracy in special work. The tables and platens are of extra length and have both a simultaneous and an independent vertical and horizontal movement on inclines, constantly retaining the proper distance from the periphery of the cutter. The tables can be separated, the outer bearings removed, and heads put on for gaining, moulding, etc. In one type of variety moulder the mechanism for raising and lowering the spindle is within the upright that supports the table, and is operated by a hand-wheel.

The Universal Wood-worker, as best known in America, consists practically of two machines—a variety wood-worker and a four-side moulding-

machine (*pl.* 16, *fig.* 9). On the wood-worker side material can be planed straight or out of wind, etc., the opposite side being a moulding- or planing-machine, on which the material is fed by power under a revolving cutter-head over a bed or platen by feed-rolls, for reducing it to a thickness or for moulding, etc. The most elaborate form of universal wood-worker is really a double machine with two independent arbor- and cutter-heads, one, upon what is known as the wood-worker side, working below the line of the bed or platens and operating on the under side of the material, and the other or moulding side having its main cutter-head acting upon the top of the material, other heads dressing the sides and the under surface. Either side may be started or stopped independently. Upon the moulder side the work is fed by power-driven rolls, while upon the wood-worker side the material is passed along by hand over a cutter-head revolving between two horizontal tables. The under head has independent adjustment, to suit the thickness of the cut, and, with the side heads, raises and lowers vertically with the platen or bed. A hand-planer has its cutter-head and arbor solid and turning in stationary bearings between two tables having vertical adjustment to and from the path of the cutters.

Work of the Universal Wood-worker.—Some of the various kinds of work that can be done on the universal wood-worker (*pl.* 16, *fig.* 9) are exhibited on Plate 17—namely, planing out of wind (*fig.* 6); tapering (*fig.* 7); box chamfering (*fig.* 8); cornering (*fig.* 9); ordinary chamfering (*fig.* 10); squaring up newels or balusters (*fig.* 11); angle gaining (*fig.* 12); rabbeting (*fig.* 13); ploughing (*fig.* 14); hand-matching (*fig.* 15); joining and mitring (*fig.* 16); raising door-panels (*fig.* 17); circular moulding (*fig.* 18); making heavy mouldings (*fig.* 19); and ripping (*fig.* 20). The positions of the machine, of the material, and of the hands in such work are also illustrated in the Figures.

Outside Moulding-machines have the bed, with two or three heads, outside the frame; inside moulders have all the heads and table inside the frame. Outside moulders are the kind most frequently used, and can be adapted for other work than moulding, as flooring and ceiling stuff. The universal wood-worker in its best forms is a combination of the outside moulder with a machine for planing out of wind, grooving, etc., and for all kinds of straight work.

Edge-moulding Machines have their heads placed vertically in a table and are designed for moulding the edges of carved work. These machines are made with one or two spindles; single-spindle machines should be made to reverse their cutting direction while in operation.

Carving and Recess-moulding Machines are for face moulding or working forms of panels in the surface of the work. They can be adapted to general use in edge moulding.

Safety for life and limb to operators of variety moulders is very largely increased by a device for holding the work on the table. The stuff is held down by a wood block forming an arc or segment of a circle and

attached to two arms of spring steel, which are fastened at the other end to the ends of a cross-head, which may be moved up and down in vertical ways by a screw and hand-wheel, the frame in which the cross-head slides being bolted or clamped to the machine-table.

Routing is the removal of material by a bit which is somewhat like a boring-drill, but which cuts both with edge and with bottom, and is given, relative to the work, a motion of translation. The analogue of the routing-tool is found in the cotter-drill, referred to under metal-working machinery (p. 118). Routing proper is done only in routing-machines and in some varieties of mortising-machines (p. 88), although many kinds of carving and panelling are really only routing.

Turning is the removal of material from the external surface of a rotating piece or from the interior of a hole therein; it is principally employed for the production of objects of cylindrical sections, although elliptical and irregular objects may also be turned. Turning is done only with machines called lathes, or in special machines which combine the functions of the lathe with those of other machine tools, and these may be automatic or not. They are described in full detail under the head of metal-working (p. 105). The same general principles are employed in wood-working lathes as in those for metal, but the gauge- or copying-lathe has for its special design the duplication of objects of a definite outline.

Turn-benches and Lathes.—For producing articles of circular cross-sections machines such as are represented on Plate 20 (*figs.* 1, 2) are indispensable auxiliaries. The material to be worked is revolved, generally, around a horizontal axis, while a turning-tool, supported in a suitable rest and made to act upon its periphery, detaches material in the form of turnings or shavings. As each point of a rotating body describes a circle, all cross-sections of the material at right angles to its axis must become circles, provided the distance of the tool from the rotating axis be not changed during the rotation. By giving the tool, during the rotation of the work, a motion parallel to the axis, there will result a helical cut whose separate convolutions, lying closely together, form a cylindrical surface, and by changing the course of the tool conical, straight, spherical, or other surfaces may be produced.

Turn-bench.—The oldest and simplest arrangement for turning is the "turn-bench" (*fig.* 1), at present used only for shaping very small articles, such as ebony, bone, or ivory chessmen, or the cylindrical parts of the works of clocks and watches. The piece to be shaped is secured between two conical steel points held in two poppets, one of which is fixed to a bar, which may be secured in a vise, while the other can be shifted upon this bar according to the length of the piece to be worked. Upon the work to be shaped is placed a small pulley, around which is passed the cord of a drill-bow. By drawing the bow to and fro with one hand the work to be shaped is rotated first in one direction and then in the opposite direction, while the removal of the turnings is effected by a tool held in the other hand and supported by a rest on a T-rail which

extends from one poppet to the other. Formerly turn-benches in which the work was rotated by a treadle were much used. A cord fastened to the treadle passed two or three times around the work and was attached to the end of an elastic pole or lath (hence the term "lathe") fixed above the head of the turner.

Lathes.—Since the turning-tool can act upon the work only during the rotation of the latter toward the tool, half the time is lost by the use of the turn-bench, and turning contrivances at the present time are exclusively used for giving an uninterrupted rotation in one direction. The principal types of these contrivances (lathes) are represented on Plates 20 to 23.

Foot-lathe.—In the ordinary foot-lathe (*pl.* 20, *fig.* 2) a driving-shaft, resting in the lower portion of the frame and connected by a cord with a mandrel in the upper portion, toward the left hand of the turner, is rotated by a treadle. The piece to be shaped is so attached to this mandrel as to rotate with it. Long pieces of work are supported on the centre of the outer end by a pin fixed in the so-called "sliding poppet," whose distance from the head-stock or mandrel-stock can be varied according to the length of the piece to be shaped. The tool is held by both hands, with a "rest" as a support, and thus forms a lever upon whose short arm falls the resistance of the material, while the hands of the turner act upon the long arm. These foot-lathes are about the same for wood-working as for metal-working, the principal differences being that for wood the rotation speed is higher, and the method of attachment to the mandrel is usually by points projecting from the live spindle instead of by bolts, or by projections in the face-plate of the lathe, or by "chucks" which grasp the periphery of the object held.

Foot-lathe Tools.—Different shaped tools used with such lathes are shown in Figure 3, the first six serving for "turning" proper and the last two for cutting screw or circular threads in previously formed cylindrical or conical surfaces. Figure 33 (*pl.* 13) shows a number of hand-turning tools for turning hard-woods, ivory, and brass. (See p. 105.)

Gauge- and Copying-lathes.—The wood-turner no longer uses calipers to gauge the depth of cut and regulate the outline or profile of his work, nor is he limited to the production of shapes which are circular in every cross-section, for he can employ lathes which, while turning out objects that are thus circular in every transverse cut, insure perfect profile and size; and he may also turn out such irregularly shaped objects as axe-helves, gun-stocks, etc., the machine not only regulating the depth of cut and the profile, but also producing the desired amount of eccentricity and non-circularity of cross-sections. But the gauge- and copying-lathe of to-day are considerably in advance of those of a decade ago (*pl.* 20, *fig.* 9), and America, which originated these types, still leads the world therein. In gauge-lathes a desirable feature is a small guard upon the follower, which regulates the thickness of the shaving taken by the finishing-knife and prevents the knives from digging into the stick. Another good ele-

ment in some of these machines is that the head- and tail-blocks are milled out to fit the ways and have a bearing over their full extent, so that the blocks can be set their entire length over the ends of the bed and turn longer than the regulation length. Shorter blocks than the maximum can be turned by moving the tail-block up toward the head.

In an improved Blanchard copying-lathe (*pl.* 18, *fig.* 9), for spokes, handles, etc., the vibrating frame travels along by a feed-screw, cutting the round and oval parts of the spoke in conformity with the pattern. Arriving at the square end of the spoke, the feeding speed of the cutter-head and the number of revolutions of the spoke and form are automatically reduced; the square end is next cut, and the cutter-head then stops. The vibrating frame is then automatically thrown out of reach of the cutter-head, which immediately returns at a much increased rate of speed.

A very simple automatic gauge-lathe (*fig.* 10) employs sheet-iron profiles of the finished article instead of a pattern like (or larger than) the object to be made. This, of course, does not answer for work not circular in every cross-section. One type has two cutters to the sliding-rest and one sizing-ring—that is, one cutter to size the stock so as to fit the ring, and one to rough out the stock, the latter being controlled by a pattern which is fastened underneath, and which is an exact profile of the finished articles. The back knife slides in planed ways and the finishing-cut is made by an inclined vertical knife, which works on the back of the piece to be turned and is so connected with the sliding-rest that as the rest moves forward the knife is gradually brought down and follows immediately after the roughing-cutter. In some machines the connections between the dogging- and releasing-rods and the tail-spindle lever are ball-joints, which play in all directions, thus working easily and obviating any tendency to bind in the jaws.

For such very irregular forms as handles for axes, picks, hammers, etc., one gauge-lathe (*fig.* 11) has the wheel, which follows the pattern, upon the same rocking axis as the cutting-tool, the pattern being fed along. The cutters are guarded, so as to avoid danger to the operator. The pattern regulates only the form of the finished articles, their size being varied by vertical adjustment of the rest upon which it revolves, so that the same pattern will turn out articles of several sizes of cross-section, but having the same length and the same form of outline. Such a machine will carry as cutting-tools either saws or cutter-heads,—saws being best for very crooked articles, like axe-handles. As it works only to size, this machine must be followed by a scouring-belt, for finishing the surface.

Rod-and-dowel Machines, for turning from end to end articles of circular cross-section and uniform size, such as chair-stretcher rods, dowels, ladder-rounds, curtain-rollers, poles, etc., have feed-rolls both front and back, these serving the double purpose of feeding the material along and holding it in line. A reversing arrangement permits defective pieces to be backed out. The stick is fed through a hollow cutting-tool and through its mandrel. The rolls in front are adapted to feed square sticks, taking

them corner-wise; those behind have grooves for round sticks, these requiring to be changed to suit sticks of different cross-sections and diameters. A recent type (*pl.* 18, *fig.* 1) has vertical feeding-arbors, which are rather more correct than the horizontal in centering the stock, and will turn all sticks round that are as large as the finished size. In changing from one sized stock to another no adjustment of screws or parts is necessary, an independent cutter-head and a set of rolls being provided for each size. There are three speeds of working-feed and a reverse feed.

Wood-bending.—Recent construction employs bent wood much more largely than formerly, thereby replacing sawed forms of irregular shape or built-up members with mortised and tenoned joints. Bent wood is now largely used in wagon-, carriage-, and car-building, chair-making, etc., and it has even been seriously proposed for ship-building, to replace by bent members all knees and other curved timbers. A steam-box makes the wood pliable, and when cold it retains the form into which it was bent while hot. Recent machines bend small articles around hollow steam-heated "formers," thus doing away with the necessity of opening a steam-box and maintaining tight joints therein. In bending shafts the formers and beds are arranged in sections each to hold ten shafts, one section right- and the other left-handed (*pl.* 16, *fig.* 8). All twenty shafts get vertical curvature around a drum, as in plough-handle bending, and the lateral bend is accomplished after the shafts have been brought down to the horizontal plane and the vertical bend is formed. Both the former for the vertical bend and the bed for the horizontal are hollow and steam-heated. In a recent plough-handle bender the formers are cast in one piece, making a cylinder to admit steam. Upon the periphery of this there are fifteen grooves of proper depth to suit the inside shape and circle of the handle, and at the terminus of the grooves there are cast lugs for long hooks. Each handle is placed in a socket and bent by a lever over a former and allowed to remain in place two and one-half hours, after which the handle will retain its shape in any climate. A bending-machine for felloes and handles consists of a vertical frame bearing a somewhat circular former and adjustable in height. Below this there is a hinged frame.

Smoothing proper, or polishing, is distinguished from other surfacing in that it little alters the dimensions, proportions, or shape of the article worked upon. It is done with sand-paper, emery-paper, or glass-paper, and by emery-wheels, the latter being used only in machines and the others both in machines and by hand. Examples of machines smoothing by the aid of sand-paper are shown in Figures 2 and 3 (*pl.* 18); and of those employing emery-wheels, Figures 8 and 9 (*pl.* 19). The resultant waste is in the form of fine dust.

Compressing is done by punches used in the hand in connection with a mallet, or by rollers or dies bearing a pattern in intaglio or in relief. This class of work is for ornamentation only, and there is no waste. It is very considerably employed in the cheaper grades of furniture and in architectural decoration. Another and special class of compression,

employed in making round-sectioned match-splints, is done by forcing the wood block end-wise through holes in a steel die-plate.

Pressed moulding, on which there is a pattern like that made by carving-tools, but not under-cut, is made by passing moulding which has approximately the desired cross-section between two rolls, one plain and the other incised with the pattern designed to be raised. Good types of such machines have adjustments for pressing curved panels used in chair-backs, leaving a plain margin all around the figure.

Wheel-making Machinery.—Modern construction runs so largely to special machines and to making interchangeable parts in multiplicate that a large class of machines has been produced to effect this end in almost every important branch of manufacture—notably in making carriage- and wagon-wheels. Some of these are very ingenious, and their work is more rapid and accurate and better finished than would be possible by hand.

In an improved wheel-tenoning machine (*pl.* 18, *fig.* 5), for equalizing spokes and tenoning them after they are put in the hub, the "spider" is held between two cup-like clamps. By the motion of a treadle one spoke is grasped near its end between two V-shaped jaws; an equalizing saw with its mandrel at right angles to the axis of the wheel cuts off the spoke-end. This saw is mounted upon a hollow arbor and has in its centre a hole, through which the tenon-cutter passes, the saw being held to a face-plate by countersunk screws. By a one-hand lever the saw is brought across the tenon-end, and by another the tenon-cutter is advanced. The clamps which hold the hub are mounted upon two sliding bars, to permit adjustment for different diameters of wheels. Both hands of the operator are free to work the auger and revolve the wheel.

For boring rims and felloes there is employed a machine with horizontal auger, the rim being held upon a semicircular table, which is reversible, so that boring can be done from either inside or outside. There are gauges to regulate the distance between holes, and the rim or felloe is shifted around against a set of friction guide-pins which determine its centrality. For curving and finishing the inner curve of rims and felloes a machine is used having two adjustable mills with their edges somewhat circular (*fig.* 4). The cutters are set closer together or farther apart for different thicknesses of felloes. The edges of rims and felloes are planed in parallel planes by passing them between two horizontal cutters, a curved feed being given by forming-plates and the feed being effected by readily set live-rolls. The angle of the feed-rolls can be changed to suit different wheels. The knives are set at an angle for a shearing cut, thus producing smooth work and preventing tearing. Bevelled rims are produced by tapering cutter-heads.

A hub-roughing and finishing machine (*pl.* 16, *fig.* 4) clamps the block between a live and a dead cone-spindle, the former being rotated by a friction disc. A table having transverse motion bears two stands, one having fastened to it a roughing-knife and the other, upon the opposite side of the spindle, bearing a set of knives of proper shape to finish

the hub. All the knives stand at the angle at which an experienced finisher would hold a hand-tool to do the best work. The roughing-knife has its cutting-edge down. In the hub-boring machine the hub is clamped horizontally between two V-shaped jaws, and the auger is run down through it by a rack-and-pinion feed, the overhead pulley being a drum, to accommodate the lengthwise motion of the auger. Taper reaming of hubs is done in a machine having cup-shaped clamps for the hub ends, the two clamps being held upon a carriage having motion in a line with the axis of the hub. A taper reamer receives rotation from a shaft at the other end of the machine. The work is fitted by clamping the hub in position and moving the carriage along by rack-and-pinion feed operated by a hand-wheel. Elm hubs are sometimes bored before roughing, the machine somewhat resembling that for reaming, except that the blocks are held between steel spurs instead of cups.

Hub-polishing is accomplished upon a machine having two cone-headed spindles, of which the head or live spindle has no lengthwise motion. The carriage bearing the tail spindle is moved back and forth lengthwise by a treadle, a counter-weight serving to make the work easier. The live spindle need not be stopped to put in or take out a hub. A sand-belt machine for smoothing irregular work has one of the pulleys which bear the sanded belt adjustable in distance from the other, so as to keep the sand-belt tension just right, the tension being applied to the belt by a large square-threaded screw. Sanding and equalizing wheel-treads are done by turning the wheel while held horizontally in contact with a large sand-covered vertical disc (*pl.* 18, *fig.* 2). The edges of the wheel, after assembling, are polished by passing it, while mounted upon a horizontal axis and rotated slowly, between two vertical polishing-discs, each of which finishes one side.

The Pryibil Twist-machine (*fig.* 8), for producing all kinds of straight, tapered, curved, spiral, or rope mouldings (*fig.* 7), holds the work between centres mounted on a bed fed along on a frame pivoted to the main frame, so as to slide at varying angles. The live centre has a train of change-gears, to vary the degree of twist, which is right- or left-hand according to the side on which the gears are placed. An index-plate permits of cutting from one to six strands on a piece. The cutters are like the bits used on variety shapers, except that they are inclined 45° to their collars, so as to give them a shearing cut from the outside of the work to the centre. A hand-feed is purposely employed instead of a power-feed. The latter would not dispense with an operator, but would, on the contrary, call for a more skilled and careful attendant properly to care for the extra complication and to exercise proper precaution in setting the stops and making the adjustments so as to avoid accident. Furthermore, hand-feed will turn out more work, as a rapid rate can be maintained at the start and finish, where the work is strong through being near the supporting centres, and a slower rate employed toward the middle, where the work would be too weak to stand the rapid rate.

Carving-machines work from either the upper or the lower side of the material. The upper side is for some reasons preferable, because the work can be better held to the bed and it enables the operator to see what he is doing. In good machines of this class the cutter revolves in bearings practically fixed in an overhead arm, and the table has vertical adjustment, to suit various thicknesses of stuff. The spindle has above the cutter a guide-collar, to admit of the use of any sized cutter without changing the collar. In surface-panelling the pattern is placed above the work. For edge-moulding there is in the table an adjustable bearing, to furnish support for the lower end of the cutter-spindle. The cutters turn either right or left, cutting both ways. This reversibility is necessary in working most kinds of wood, as it permits of changing the direction of cut to suit the grain.

Surface-ornamenting Machine.—A special machine for surface-ornamenting, together with illustrations of its work, is shown in Figures 1 to 5 (*pl.* 17). The frame is in a single piece, of column form, with a projecting neck, which has on its extreme end an opening, on which is fitted a cylindrical sleeve-bearing, which carries the carving-spindle. The arbor can be readily moved as a radius in any direction in a horizontal plane, or may be clamped by thumb-screws on top. The driving-pulley is on the arbor, in the centre of the sleeve-bearing, and is belted from above. The arbor carries spurs and other carving-tools such as are shown in Figure 1.

The Drawer-fitting Machine (*pl.* 18, *fig.* 3) has two sandpapering discs with horizontal axes in line, the faces of the two discs opposing each other. These discs are separately belted; the frame in each revolves, being adjustable, so as to control the distance between the disc-surfaces. The discs being brought to the distance apart desired for the width of a drawer, each drawer is fed through between them upon sliding ways, which are adjustable in height, so as to bring each drawer, no matter what its depth, with the centre of its depth in line with the rubbers of the polishing-discs.

Miscellaneous Wood-working Machines.—A joint-cutter and planer has a die with a right-angled opening; against this there work two blades, which stand at right angles to each other, and each of which has a drawing cut. These, being brought down by a lever, cut from the obtuse toward the acute corner of the moulding or other object to be mitred. Both joints are cut at once. Handles and such articles are smoothed by a tumbling-machine, which is best constructed with an iron frame and heads, so that the wooden staves may be taken out and replaced, when worn, without disarranging any of the iron-work.

The automatic car-gaining machine (*fig.* 6) has a long bed with a table having lengthwise travel. Parallel with the track of the table is the spindle of the arbor-head, and this has traverse across the table. It also has vertical movement, to accommodate different thicknesses of timber and depths of cut. The sliding frame, which bears the cutter-arbor, has automatic feed and may be stopped at any point. The table is also arranged

to be stopped at any desired point, so that exact duplicates of timbers may be produced. The gaining-head frame has a fixed speed in each direction, no matter what the width of the timber. This permits gaining in both directions. Some of these machines have attached to the side of the column a vertical spindle, for boring timbers and sills after the gaining has been finished. This spindle has a vertical movement and a traverse over the carriage.

The traversing- or angle-gaining machine has a horizontal arbor bearing the gaining-head and traversing at right angles to the length of the bed or table. This is parallel with the spindle of the cutter-head, and has vertical adjustment to suit the thickness of timber and the depth of the gains; also angular adjustment about an axis parallel with the cutter-spindle. The traversing is done by a hand-wheel and a screw.

Machines are employed to manufacture from soft white woods long fine, fibre-like shavings, called "excelsior," which are used for packing purposes as well as for cheap upholstery. Matting-machines are used to some extent to produce stipple-like indentations as a background for relief carving.

Dovetailing-machines cut out regular dovetail mortises (leaving dovetail tenons) either by rotating cutters or by spiral saws. There are also made false dovetail joints, in which pins projecting from semicircular countersinks fit semicircular scallops having circular holes concentric therewith. Reaming-machines, which are simple boring-machines having a long pod-bit as a reamer, are used to ream the bores of hubs and to clean from them the chips that have been forced into the centre by the mortising-chisels.

Hoop-machines take ¾-inch bars sawed from a plank, point them, plane their sides and edges, and then saw them at such an angle as to make a thick and a thin edge, producing two hoops from each bar.

Conclusion.—In the foregoing pages there have been outlined some of the many general and special machines which have done so much not only to meet the demand for wood-construction, but also to foster and improve it. The labor of sawing, planing, moulding, matching, tenoning, incising, mortising, boring, bending, polishing, etc., formerly performed by hand, is now done much more expeditiously and accurately by machines, and these have not only cheapened and bettered the product of the wood-worker, but have also rendered possible the development of new countries and the success of new industries. Their busy hum has waked the echoes of the primeval forest as its giant growths have been reduced to prosaic "lumber," whose production has brought wealth and population to hundreds of wood-side hamlets, and whose conversion into the innumerable articles required on the farm, in the work-shop, and in the home has added so much to the comfort and convenience of all. In America, under the stimulus of necessity, in newly-settled communities, wood-working machines have been developed to a degree far in advance of those of any other country of the globe. (R. G.)

II. METAL-WORKING TOOLS.

All the work performed upon metals for the purpose of fashioning them into tools, implements, and appliances of various kinds is effected either by cutting, abrading (including polishing), or bending, to which processes those of stamping, flanging, and punching are related in various degrees. All these mechanical operations, more particularly those of bending, punching, and stamping, are dependent on the property possessed by all solids, and especially by metals, of spreading under pressure, and in many cases the line of demarkation between one process and another is very difficult to trace. Thus in some machines the process of cutting frequently shades off into that of abrasion and the process of stamping into that of bending.

The term "machine-tools" has by common consent been adopted to designate those machines which are employed in working iron by purely mechanical operations. They supplant metal-working hand-tools, just as wood-working machinery supplants wood-working hand-tools; but, while wood-working machines are to be considered as machine-tools no less than those for working metal, the usage of the trade has made and maintained the distinction between machine-tools and wood-working machinery.

Classification.—The principal varieties of metal-working machine-tools built in the United States to October, 1889, are: (1) *Lathes:* axle, bolt, car-wheel, driving-wheel, die-grinding, engine, forming, gun-stock, gun-hoop, hand, pattern-makers', pulley, rod, spinning, shafting, screw-cutting, turret; (2) *Planers:* connecting-rod, crank, friction, frog and switch, open-side, pit, plate, regular, rotary, valve-seat (rotary), valve-seat (reciprocating); (3) *Shapers:* crank, cylinder, double, geared, pillar, single, traversing; (4) *Slotters:* locomotive-frame, regular, screw, under-stroke; (5) *Boring-mills:* box (horizontal), box (vertical), chord, car-box, car-wheel, crank-pin, cylinder, hand-wheel, horizontal, link, pulley, tire, vertical; (6) *Drilling-machines:* arch-bar, automatic, cotter, horizontal, key-seat, multiple, portable, radial, rail, sensitive, turnbuckle, universal, vertical; (7) *Shears:* angle, bar, circular, plate; (8) *Milling-machines:* bolt-head, column, double, horizontal, key-seat, regular, steam-chest seat, universal, vertical; (9) *Grinding-machines:* cutter, lathe-centre, plain, reamer, surface, twist-drill, tool, universal; (10) *Bolt-machines:* cutting, heading, head-milling, threading, turning; (11) *Nut-machines:* chamfering, facing, milling, punching, tapping; (12) *Presses:* crank-pin, cutting, drop, drawing, geared, hydraulic, stamping, wheel; (13) *Miscellaneous Machines:* belt-polishing, centring, crank-pin turning, cutting-off, cross-head-pin turning, chucking, die-sinking, facing, forging and upsetting, gear-cutting, grooving, heading, marking, measuring, punching, plate-bending, profiling, rack-cutting, rail-bending, shaft-straightening, screw-making, quartering, rail-cutting, riveting (steam), riveting (hydraulic), riveting (pneumatic), tool-grinding, wheel-turning, wheel-quartering; and steam-hammers. It will be noted that there is a marked tendency toward

specialization. Under each head there are built for particular classes of work other forms than those above mentioned, but, not being in general use, they are not specified. Some of those named under "Miscellaneous" might, indeed, be classed under "Lathes," "Milling-machines," etc. The present section will include a review of typical machines in each of the more important classes.

Sharpening, Grinding, and Abrading Devices.—To reduce the size, vary the shape, or improve the surface of metals there may be employed abrading devices, such as the file and rasp, the hone, whetstone and grindstone, the emery-wheel, and the corundum-wheel. The character of work done by these in removing material by a gnawing action merges so closely into the work done by rotating cutters in the so-called "milling"-machine that, as regards results, each one must be considered in comparison with all the others. But the milling-machine (and, indeed, the grinding-machine) is now an instrument of precision and worthy of being ranked with machine-tools. We shall first consider the file and the rasp, or primitive hand-tools, and secondly the hone and the grindstone because they are used to sharpen edge-tools, and shall incidentally treat the grindstone as a shaping device as well as an appliance for sharpening.

Files and Rasps.—The most common abrading tools are the file and the rasp, the former being used for metal and the latter for wood, horn, and other fibrous materials. These tools, especially the file, exist in almost endless variety in length, contour, thickness, and style and fineness of cut. The file and the rasp, like the grindstone and the emery-wheel, are used to remove projections and rough portions from metallic objects in order to bring them to a desired smoothness of surface and to required dimensions. The emery- and corundum-wheels and the grindstone may be regarded as rotary files driven by power. It is not deemed advisable to give here an itemized description of all the varieties and types of rasps and files, as it would be but a mere catalogue of no special interest. Figures 1 and 2 (*pl.* 19) represent various types of files.

Vises.—To aid in properly holding objects which are being filed and ground there are employed various kinds of vises, both hand and bench (*figs.* 3, 4). The bench-vise is so called because it is fastened to the work-bench. Bench-vises are of two general classes, (1) those having a hinge, and (2) those with a parallel movement; the jaws are moved and held either by a screw or by a ratchet and clamping device. For filing and grinding these vises are generally of cast iron; for chipping they are principally of wrought iron.

Sharpening.—For sharpening small tools, such as knives, chisels, etc., there is used a stationary hone or oil-stone having a flat abrasive surface, over which is moved the material to be ground. Gouges have their concave edges worked by slip-stones having preferably concave edges of the same radius of curvature as the cutting-edge of the tool.

Grinding.—Where the article to be ground is large, as in the case of a scythe, a paper-cutter blade, a planer-knife, a saw-blade in process of man-

ufacture, or a casting having its skin and sprues worked off, it is best to have the stone in the form of a disc, which, according to the size of the piece to be worked, may be revolved by hand-power, a foot-treadle, or a belt.

The Grindstone.—Perhaps the stones of grinding-mills, as in revolving they wore each other away, suggested the use of the grindstone, which is one of the oldest tools used for changing the shape of metallic objects. It acts in the removal of numberless small particles, and is employed not only to change an original shape and outline, but also to give a polish. It is mounted upon a shaft, which passes through a square hole in the stone, and which was originally carried in boxes on a wooden frame, for which subsequently an iron frame was substituted. At present the stones, particularly if large, are held in place on the arbor by and between cast-iron flanges, which are slightly concave on their inner sides. Such stones run from 1 inch to 6 feet in diameter and from 1/4 of an inch to 18 inches face. Most of the grindstones used in the United States come from Yorkshire, England. There are known and used many varieties of grit, which differ in the size and sharpness of the grains and the hardness of the matrix by which they are held together. The simplest form of grindstone was mounted in a very crude wooden frame, and was kept wet by a drip from a keg or a can suspended above the stone. Subsequently the stone was revolved in a movable trough filled with water. The trough and the frame are now generally made of cast iron in one piece, while the mounting is so improved that the arbor runs on anti-friction rollers. Figure 7 (*pl.* 19) shows an ordinary grindstone-mounting. One excellent form of portable grindstone-frame is made in a solid casting of box form with two divisions, one for the water in which the stone turns and the other for clean water for cleansing tools. There is an outlet for the discharge of the deposit and a steady rest for grinding small tools. The grindstone, however, is being very generally superseded by the emery- and corundum-wheels, whose advantages are that their particles are naturally harder, their cutting-edges are not water-worn as with sandstone, the grains in any one wheel are all of a size, the softness of the matrix may be chosen to suit the work to be done, and, furthermore, they may be produced at very reasonable rates in an almost infinite variety of size and of profile.

Emery-wheels (*fig.* 8), which are practically artificial grindstones, are used to supplement the lathe and the planer in producing true cylindrical or plane surfaces. There has never been made a lathe that will turn truly *round*, nor a planer that will plane truly *flat*. In the latter respect the emery-wheel produces work of a trueness and finish which equals the best produced by the more expensive method of scraping and fitting upon planes, and which cannot be produced by lathe- and hand-work. Emery-wheels are now very largely used for grinding the treads of "chilled" car-wheels. For the production of perfectly cylindrical surfaces, as for car-brasses, an emery-wheel with semicircular convex rim does excellent work at a very rapid rate. The brasses are fed along under the machine, which, if

they are well moulded, will grind them at the rate of one per minute from the rough to a correct fit, leaving them with a fine finish. An emery-wheel to be of maximum service should be safe from bursting, should cut freely with but little heat, should be reasonably durable, as far as possible should be free from noxious dust and from unpleasant smell, should be of even density, should be of perfect profile, and should wear evenly. It should be well mounted and properly run, should be run at its most efficient speed as determined by practice and recommended by its maker, and should not have the work forced up against it too hard. No emery-wheel will run well if allowed to jump. A good rim-speed is about 5500 feet per minute. As a rule, an emery-wheel will remove in the same number of hours from twelve to fifteen times as much metal as a file. Emery-wheels are "turned" by a diamond-pointed tool consisting of a crystal of boart or black diamond firmly set in the end of a steel rod and furnished with a suitable wooden handle, or the boart may be mounted in a square rod and used as a lathe-tool.

One of the best-known manufacturers of emery-wheels classifies them according to their coarseness of grain and hardness. Class one, which is coarse and hard, is suitable for edging cast iron or steel, for taking gates and sprues from castings, and for general rough grinding. Class two, which is of medium coarseness and is hard, is about the same as class one, but may also be used to excellent advantage for chipping, moulding-knives, and lathe-tools, and for gumming saws. Class three, medium grain and soft, is suitable for grinding brass and for surface-work on steel and on cast and wrought iron. If used for edging, it will cut fast and freely, and will also wear away rapidly. Class four, which is hard and of medium coarseness of grain, is for grinding not only upon light work, but also upon all work which will not affect the shape of the wheel. Class five is used for grinding upon brass or other soft metals, for polishing fine surface-work on iron and steel, and for sharpening tools. An extra class, good for "gumming" saws, is moderately coarse, soft and of open texture, and grinds freely, while it generates but little heat. The ordinary emery-wheel frame, which so effectually supplanted the grindstone in most of its uses, has in the performance of good work been superseded by the universal grinding machine.

The Universal Grinding-machine (*pl.* 19, *fig.* 9) has importantly modified machine-shop practice, as by grinding it readily gives an accuracy in finish previously considered commercially impracticable, and, moreover, demonstrates that most conical and cylindrical surfaces, soft or hard, can be better and more economically finished by grinding than by any other process. In many kinds of work it takes the place of a lathe, which it supplements by finishing other work previously roughed out. It does both internal and external grinding, straight or taper, and finishes spindles, arbors, either straight or angular cutters, reamers, jewellers' rolls, hardened boxes, and standard plugs and rings. The sliding table (*A*) rests upon the bed (*B*) and carries the swivel-table (*C*). Thus, for grind-

ing tapers, the line of centres of the head- and foot-stock can be set at any angle with the sliding table without throwing the head-and-foot stock-spindle out of line. The table (*C*) is provided with an adjusting screw (*D*) and a scale showing the taper both in degrees and in inches per foot. The wheel-bed (*E*) is mounted upon a knee (not shown in illustration), and may be set at any angle from 0° to 90° on either side of the line at right angles with the sliding table. The semi-circumference at the lower edge of the wheel-bed is graduated in degrees. The wheel-slide rests on the wheel-bed. The table may be fed and reversed automatically or by hand. The cross-feed is operated by hand. The head-stock (*F*) is attached to a base-plate (*G*) bolted to the swivel-table (*C*), and is made to swivel about a centre-pin. The circumference of the swivel-table at its lower edge is graduated to degrees. A friction-brake enables the driving-drum to be stopped almost instantly. The swivel-table can be moved to either side of its central position to grind tapers from 0 to 2 inches per foot and from 0° to 10° in angular measurement. For grinding work on the face-plate or chuck the head-stock can be set at any angle within the whole circle. Work can be revolved upon dead centres or upon one dead and one live centre. Two tapers can be ground, either external or internal, without changing any of the settings. Ample provision is made for wet grinding.

Turn-benches and Lathes.—The turn-bench is the most primitive machine-tool for producing articles of circular cross-sections by removing shavings or turnings from the exterior of the partly finished piece with a non-rotating tool while the work rotates. The principles of design, construction, and operation of the turn-bench and of the plain continuously-rotating foot-lathe with simple tool-rest have been described at length under the head of wood-working machines (p. 88), the former being illustrated in Figure 1 (*pl.* 20) and the latter in Figure 2. In metal-working the tool requires firmer holding and guidance and the machine a slower rotative speed for a given diameter of the piece to be worked, although the speed varies with the hardness and other physical characteristics of the metal, with the width and the depth of the cut, and with other conditions familiar to the expert machinist.

Lathe-tools for Metals.—Tools for turning and boring metals in a lathe are practically the same as those required in a reciprocating metal-planing machine. They have more obtuse angles than wood-working tools, and are made heavier not only that they may have sufficient strength, but also that they may carry off the heat engendered by the work of cutting. This heat is considerable under many working conditions, notwithstanding the use of oil, water, and various solutions applied at the point of cutting to lessen friction and at the same time to cool the work by convection. A description of the hundred or more varieties of metal-working lathe-tools for roughing, finishing, screw-cutting, boring, and chasing the different grades of wrought and cast iron, steel, brass, etc., would require a treatise in itself; we shall, therefore, briefly describe a few of the more usual and

important tools, after noting the general principles governing their form and use. They require that for a given acuteness the strength of the cutting-point or edge be kept as great as possible by its lower face (that along which the chip or shaving does not pass or the face next the newly-cut portion of the circumference), being kept, at the point of cutting, at the maximum possible angle with the tangent to the work, leaving merely the necessary clearance between the work and the tool-face, and keenness being obtained by inclining the cutting-face as little as strength will permit to the same tangent.

Figure 33 (*pl.* 13) shows a number of hand-turning tools for turning hard-wood, ivory, and brass. Number 1 is a "milling" tool for impressing a circumferential ornamental line on work previously finished. Numbers 2 and 3 are chasers for cutting fine screw-threads internally and externally respectively. Numbers 4 and 5 are bent "inside" tools; number 6 is a flat tool for outside work; number 9 a "point" and number 10 a "round-point" tool; number 11 is a square graver; number 12 is for "cutting off" and numbers 13 and 14 are for general turning.

Referring to Plate 19 (*figs.* 5, 6), number 1 is known as a "left-side" tool; number 2 is the same style, made "right hand." Numbers 3 and 4 are the same types, "bent" for working at an obtuse angle. Number 5 is a heavy "diamond-point" tool for cast iron; numbers 6 and 7 are right-hand and left-hand diamond points for steel and wrought iron. Number 8 shows a "half-diamond point" and number 9 a "round-nose." Number 10 is a "water-finishing" tool, which takes off a very fine, wide turning. Number 11 is for cutting off pieces in the lathe; number 12 for roughing stock; number 13 for cutting external or "male" V-threads, and number 14 the same as number 13, bent. Number 15 is for turning a hollow cylinder; number 16 for cutting an internal or "female" screw-thread. All the foregoing are used in a slide-rest.

Of Figures 4 to 8 (*pl.* 20), Figures 5 and 6 are ordinary turning-tools for metal and Figure 4 one for wood, while Figures 7 and 8 are examples of a tool whose cutting-edge consists of a three-cornered bar or piece of steel set in an iron stock. This allows of very economical use of the steel and dispenses with the otherwise unavoidable forging of the entire tool.

Slide-rest Lathes.—Lathes in which the guidance of the tool is effected by mechanism instead of by hand are called "slide-rest" lathes, a simple form being shown in Figure 10 (*pl.* 20). The mandrel carries a stepped or cone pulley with various diameters corresponding to those of a similar stepped pulley on the counter-shaft, the revolving motion of the latter being transmitted to the former by a belt. The tool is firmly secured to a rest, which receives a motion parallel to the rotating axis by a lead-screw in the interior of the bed, the nut and the screw being carried by the slide-rest. The rotation of this lead-screw is derived from that of the mandrel by belt- and wheel-gearing. This arrangement is suitable only for producing cylindrical surfaces. Sometimes engine-lathes are provided with contrivances for guiding the tool in other than a straight line—for

instance, with a special guide-bar, against which the uppermost cross-slide is constantly pressed by a weight (curved slide-rest; *pl.* 20, *fig.* 13).

Double-tool Lathe.—The lathe shown in Figure 1 (*pl.* 21) differs from the preceding in two particulars. Besides the mandrel the head-stock contains an auxiliary appliance placed parallel to the mandrel, so that the former can be connected with the latter by a pair of wheels, through which the motion transmitted to the step-pulleys can be communicated in a retarded velocity to the mandrel itself. As the step-pulleys can be directly connected with the mandrel, it is possible, with the four varying diameters of the step-pulley, to give the work eight different velocities, and thus to obtain the most advantageous peripheral speeds according to the different materials to be worked. This class of appliances is described in very full detail under the head of screw-cutting lathes (p. 108).

Another peculiarity of the lathe (*fig.* 1) is the simultaneous action upon both sides of the work of two turning-tools, which, it is claimed, not only double the capacity of the lathe, but also, by the action of the tool, prevent the work from springing. To hold these two tools the carriage has two special cross-slide rests, each allowing its tool to be traversed in two directions at right angles to each other. The details of such slides are shown in Figures 11 and 12 (*pl.* 20).

Gap-bed Lathe.—To give engine-lathes the widest possible range of work they are frequently provided with a gap-bed (*fig.* 14). Directly alongside the head-stock and beneath the head of the mandrel—which must be provided with suitable contrivances for securing the work—the bed-plate is depressed within a certain length, to allow turning work, if not too long, with a radius greater than the height of the centre from the general bed-level. The advantage of this kind of lathe lies in the fact that work is most frequently either long and thin or short and thick. This lathe forms the transition to those exclusively intended for spherical or flat work of a larger diameter, the so-called "face-plate" lathes (*pl.* 21, *figs.* 2, 3), in which the work is fastened to a large cast-iron plate (face-plate) provided with hollows and T-shaped slots and screwed upon the head of the spindle. The tail-stock or sliding poppet either is placed, together with the slide-rest, upon a special bed (*fig.* 3)—which is, however, connected with the head-stock by a foundation-plate—or is entirely omitted (*fig.* 2), in which case only a special framing for the slide-rest is required. Such lathes are very convenient for turning large pulleys, gear-wheels, turbines, etc.

Wheel-turning Lathe.—The wheel-turning machine (*fig.* 4, a variety of face-plate lathe) is used for turning car- and locomotive-wheel flanges. In turning the axle the wheels and flanges remain upon it, thus forming one piece; and this, by reason of its liability to spring, requires to be driven from both sides. For this purpose each wheel is connected with a face-plate receiving independent although synchronous rotation, whereby all chatter due to the heavy cut is avoided. The slide-rests must be of sufficient height for the tools to work nearly at the height of the axle.

Copying-lathe.—There is a strong analogy between copying-lathes for metal and those for wood, the latter having, however, higher speed. One peculiar modification of the lathe allows the production of irregularly-shaped articles and copies of a pattern. Part of this so-called "copying-lathe" is shown in Figure 9 (*pl.* 20), and has some relationship to the gauge-lathe referred to under the head of wood-working machinery (p. 94). The pattern and the work to be shaped like it are secured between chucks by means of a head-stock with two spindles and a double sliding poppet, and are turned at equal speeds and in the same direction. Against the pattern there is constantly pressed a smooth-edged disc attached to the same cross-slide with the rotating cutter. This cutter, thus receiving a certain displacement from the axial line depending on the pattern, reproduces on the work, if properly set, the form of the latter. As the rotating cutter replaces, in this case, the ordinary turning-tool, this machine may be classed with milling-machines as well as with lathes. (See p. 122.)

The Engine-lathe shown in Figure 1 (*pl.* 22) has its power transmitted from the counter-shaft to a cone in the head-stock, which, when disconnected, revolves loose upon the main spindle. If moderate work not requiring much power is to be performed, the cone is connected to the spindle by a small clutch between the large gear on the spindle and the inside edge of the cone. If great power is needed, the clutch is unlocked and the back gearing engaged, which considerably multiplies the power. The "work" is placed between the centres, the tool being held in the tool-post and guided by the several hand-wheels in the apron-carriage and compound slide.

For cutting threads combinations of change-wheels are placed at the end of the live head, to connect the spindle with the screw in such ratio as the index-plate on the lathes shows will be the result. Means are provided in the apron for automatically running the carriage to the right or to the left and for moving the tool in or out, for cross-feeding. The bed of this lathe has a hollow and double centre-rib, which stiffens it, while adding comparatively little weight.

The Screw-cutting Lathe (*fig.* 2) is intended for the production of circular work of all kinds in metal up to an extreme diameter of 62 inches, or of 46 inches should it have to rotate over the carriage. The machine consists of a combination of mechanisms, (1) for imparting motion to the work (the *live head*), (2) for holding and guiding a tool (the *carriage*), (3) for imparting motion to the tool in given ratio to the motion of the work (the *feed*), and (4) for supporting the outer end of the work (the *dead* or *poppet head*), the whole being supported on a long box-like frame called the *bed*.

The *live head* consists of a framework containing a cone pulley (A) running upon a horizontal shaft or live spindle (B), on the outer end of which is a large circular face-plate (C) provided with slots, to secure work to it by means of bolts. It is necessary, on account of varying sizes of work, to be able to vary the rate of motion of the face-plate; and to secure

this end there is used a series of toothed wheels, known as the "head" gearing. The "cone" pulley is made up of five faces of different diameters and is driven by a belt from a similar stepped pulley overhead in which the sequence of sizes is reversed. By the transfer of the belt from one to another of these diameters five changes of motion are obtained. To obtain still other changes there is used a "back" gearing, consisting of a train of four gears, starting from a small gear on the end of the cone pulley, running into a large wheel (*D*) on the back gear-shaft (*E*); this latter carries a small gear (*F*), which in turn meshes with a large gear (*G*) on the live spindle or into a large gear (*H*) on the triple-gear shaft.

Five changes are imparted by the "back" gearing and five by the "triple" gearing, thus giving, with the pulleys, fifteen changes to the face-plate motion. The "triple" gearing is effected by the small gear *F* driving the large gear *H*, which is on the shaft *J* with the small gear *K*, which drives the internal toothed surface of the face-plate *C*. When any one of these series is employed, the others must be kept idle or "thrown out of gear." As the spindle always receives the same motion as the face-plate, it is necessary to allow the cone to run freely on it; but the gear *G* is tightly fastened to it and can be locked to the cone pulley, thus imparting the motion of the latter directly to the face-plate. When the "back" gearing is used, the cone is unlocked, and the motion then comes to the spindle and face-plate, as before, through the gear *G*, but very much reduced, by reason of the ratios of the gears through which the motion has come. When the "back" gearing is not in use, the gears *D* and *F* are moved lengthwise on the shaft *E*, one to the left, the other to the right, thus throwing them out of gear and allowing the cone pulley to be locked again to the gear *G*. When the "triple" gearing is in use, the cone pulley is unlocked, the gear *D* is pushed into the small gear, on the end of the cone pulley, and the gear *F* moved until it comes into line with the gear *H*. This gear (*H*) is mounted on the shaft *J* carried in eccentric bearings, which have already been thrown down, so that the small gear *K* engages with the toothed surface of the face-plate. The moving of the gear *F* into line with the gear *H* engages them, thus completing the series or train to the spindle and face-plate. When the "triple" gearing is not in use, the shaft *J* is thrown upward by its eccentric bearings, and so the pinion *K* is out of gear with the face-plate, thus allowing the other gears to be used freely.

The next point is the carriage, which consists of a platform (*L*), bridging the bed and called the "saddle;" of an apron (*M*), containing the means of obtaining motion; of a cross-slide (*N*); of a swivel-piece (*O*) and of a tool-slide (*P*) provided with bolts, to secure the tool. The motion of the tool-slide is effected by a screw worked by the handle *Q*, and by rotating the swivel-piece *O* it can be moved at any angle to the face-plate in a horizontal plane. The cross-slide *N* can be moved by a screw, which can be worked either by the handle *R* or by power through the gears inside the apron controlled by the hand-nut *S*. Its only motion is

parallel to the face-plate. The saddle can be moved along on the bed (only at right angles to the face-plate) in three ways: (1) by hand, with the hand-wheel *W* and appropriate gearing in the apron working into the rack seen on the edge of the bed; (2) by power through a train of gearing driven by a groove cut in the lead-screw *X* and working the rack on the side of the bed, being controlled by the hand-nut *T* (both this power-feed and that on the cross-slide can be reversed or stopped by moving the lever *U* to one side or the other or stopping it in the middle); and (3) by closing a segmented nut (made in two pieces) upon the thread of the lead-screw *X* by means of the handle *V*.

The feed is driven from the back end of the live spindle by the gear *1* working into the gear *2* on the shaft *3* carrying three gears keyed fast, as shown. On a shaft (*4*) below these and meshing with them are three loose gears, any one of which can be fastened to the shaft by a sliding key operated by a clutch-pin (*5*). On the other end of the shaft is a gear which imparts motion to the lead-screw *X* through an appropriate train of gears, and thence to the carriage.

The dead or poppet head consists of a spindle (*10*), of a top piece (*11*), and of a base piece (*12*), the whole being firmly clamped to the bed by means of bolts (*13*). It is necessary for the spindle (*10*) to have a lengthwise motion; and this is imparted by a screw operated by a hand-wheel (*14*) and a pair of gears (*15*). The whole head can be moved along on the bed by a pinion gearing into the rack on the side of the bed and operated by the ratchet-lever *16*. The top piece *11* can be moved transversely across the bottom piece *12*, thus throwing one end of the work nearer the tool than the other and thereby producing conical surfaces. Both spindles (in each head) have inserted in their ends pointed pieces, called "centres," upon which the work is supported.

When work is slight or cannot be reached by the dead centre or is very long, it is customary to use what is known as a "steady-rest." This consists of a base piece (*20*), which can be firmly clamped to the bed, of a top piece (*21*), and of three steel pieces (*22*), called "jaws." These pieces, which are adjustable, can be moved by screws until they touch the work, and can then be clamped; they then provide a bearing which supports and steadies the work. To get the work in and out of this conveniently the top piece *21* is made separate and can be entirely removed, thus allowing ample room for handling. It will be seen that this machine provides a variety of speeds of rotation of the work, a variety of rates of power-feed to the tool, supports for the steady running of the work, and movements to the tool by means of which true cylindrical, angular, or flat surfaces may be produced.

Turret Screw-cutting Lathe.—Of screw-machines one of the best is represented in Figure 3 (*pl.* 22), which is a lathe having a hollow spindle with a chuck on each end, a carriage having hand and power movement and carrying two tools and a set of open screw-cutting dies, and a slide-tool block having four variations of feed and carrying six tools, to be applied

to the work successively, these tools being mounted in a "turret," so called because it resembles the turret or tower of the "Monitor" pattern of iron-clad vessels of war. This lathe will work upon any kind of pieces which can be held in a chuck and which need the successive operation of several different tools. But, while in many features it resembles a lathe, it is unlike the latter in its treatment of small work. A lathe takes a forged shape and trims and alters it; the screw-machine takes the roughened bar and finishes the product, doing the work of blacksmith, helper, fire, bolt-header, centring-machine, lathe, lathe-chucks, and even making the hole in which the lathesman tries his work. While it wastes iron, it saves labor, which is of much more value than the iron wasted. In this machine there is a chuck (*A*) with V-jaws, which is fast upon the whole arbor of the machine. There is a steadying-chuck (*B*) on the rear of the arbor, and an ordinary lathe-carriage (*C*) slides upon the bed and is worked by the usual hand-wheel (*D*) and rack-pinion. Across this carriage slides a tool-rest (*E*) worked by a screw and having two tool-posts, one in front and one in rear of the work. This tool-rest works upon an intermediate slide, which fits and slides in the carriage, and is moved in and out a short distance by a cam lever (*G*), an apron on the front end of the slide carrying the lead-screw nut *H*. Resting the cam lever brings the slide outward, and the tool-rest *E* comes with it, and at the same time the nut leaves the lead-screw. The inward movement of the slide is always to the same point, thus engaging the lead-screw *I*, which does not extend to the head of the machine, and resetting the tool. The gear is never changed, different lead-screws being used for different threads. The turret *O* turns on a block (*M*), which slides on the bed; it has in it six holes, to receive sundry tools, can be turned to bring any of these tools into action, and is secured by the lock-lever *P*. The turret slide is quickly moved by hand through the capstan levers *U*, which also lock it at any point.

In making a screw the following are the operations of this interesting and valuable machine: The bar is inserted through the open chuck and set against an end-gauge in the turret. The front tool in the carriage cuts the end of the bar; a turning-tool in the turret reduces it at one heavy cut to nearly the right size; a "sizer" brings the body to the exact size, and, an arm with an open die being brought down, the bolt is threaded; a solid die brings it to the exact size and cuts the full thread to the exact point desired; the front tool of the carriage chamfers off the end thread and the back one cuts off the bolt. The bolt being then reversed in the chuck, the top of the head is water-cut finished by a front tool in the carriage, this last operation being deferred until all the bolts of the lot are ready for it. This machine also taps nuts and makes a large variety of lathe-work.

The screw-machine exhibited in Figures 1 to 7 (*pl.* 23) is also made for the cheap and rapid manufacture of a very great variety of work of circular cross-section directly from bars of material such as steel, iron, brass, and hard rubber. Some samples of its work, consisting of screws, nuts, and studs, are shown in Figure 7. Bolts and set-screws with hexagonal or

square heads are obtained by using stock of that cross-section. Small castings having holes and studs of various shapes and sizes to be finished can sometimes be worked up with great saving of time and labor over the lathe and drill-press. The speed with which these machines will turn out work depends upon the size and shape of the work and upon the material used. Screws such as are shown in Figure 7 (*pl.* 23), if made of iron, can be manufactured at the rate of from fifty to ninety per hour; if of brass, from seventy to one hundred per hour.

The machine (*fig.* 1) is operated by working three levers, the workman standing so that one is in front and one at each hand. The lever at the left operates the *wire-feed*. This mechanism, while the machine is running at full speed, so feeds forward the rod, from which the screw or other piece has been made, as to furnish just enough stock to make another. The handle at the right operates the turret-head, bringing successively six tools to act upon the stock. The centre handle operates the cross-feed and governs the action of two tools, one usually a tool for chamfering, grooving, or knurling, and the other for cutting off the finished piece. In working wrought iron or steel a lubricant such as oil or soda-water is used. To keep the tools sharp longer, so that the work will have a smoother and more accurate finish, a reservoir of oil is provided as shown in the cut. Into the basin-joining part of the frame of the machine is drained the oil, which is strained free from chips and dirt by running through wire gauze into the large tank, from which it can be drawn and used repeatedly, thus reducing the waste to a minimum. The workman starts the machine, adjusts the speed by shifting the belt to the correct step of the cone pulley, opens the valve of the oil-reservoir and adjusts its position until the oil drops at the right place, and gives a double oscillation to the wire-feed lever, by which the stock-rod is loosened, fed forward against a stop in the turret-head, and clamped. Then at each double oscillation of the turret-head lever a new tool designed to do a special part of the work is presented to act upon the stock-rod, and by a double oscillation of the cross-feed lever the piece is chamfered or grooved and cut off, and the machine is ready to recommence the cycle.

Figures 2 and 3 show the wire-feed in detail. The steel spindle *a* (*fig.* 2) is hollow, to allow the hollow rod *b* to pass freely through it, the hole through *b* being a little larger than the largest stock that the machine is designed to work. The conical part of the carefully tempered spring collet *c* fits into a hole ground to a corresponding taper in the hardened steel shell *d*. Putting *b* in the spindle at *k* so that the surfaces c' and b'' coincide, and screwing *d* on the spindle at *k*, then, by pressing upon the end of the rod b', the conical parts of *c* and *d* will coincide, forcing together the three jaws of the spring collet *c*, and clamping the stock-rod passing through it. Collets with different holes are required for different sized rods. The stock-rod has a continual tendency to go forward against *c* (*fig.* 3) because of the force transferred from a weight through the bronze

chain *a*, over a small pulley to the piece *b*, which slides freely upon the rod *c*. By turning the disc upon *b*, various sized holes can be brought successively to a common centre, thus forming a very convenient bushing for different sizes of stock. By withdrawing the pressure from the rod *b*, the spring collet will retract, allowing the stock-rod to pass through until arrested by the stop in the turret-head, and by renewing the pressure the rod is again clamped, and the turret-head and cross-feed may proceed with their functions. To reciprocate these pressures while the machine is running, the rest of the mechanism shown in Figures 2 and 3 (*pl.* 23) is necessary. In Figure 2, *c* fits loosely upon the spindle *a*, as shown in position in Figure 3. The piece (*fig.* 2) is virtually a part of the rod *b*, the connection being made by screw-pins (*f*) passing through the slot in the spindle *a*, into holes (*b'*) in the rod *b*. Hinged to *f* are two tempered steel cam levers, which act against the bevelled surface of the hardened steel nut *g*, forcing the rod *b* forward; the nut *g*, after proper adjustment, is held in position by a set-screw pressing a shoe against the threaded spindle; *i* is the fulcrum, which is screwed firmly into the frame of the machine. The steel yoke *h* has one surface of brass, which can be replaced when worn. The cone is fastened to the spindle, so as to allow adjustment with its axis by means of a nut (*k*), the thrust being taken in both directions by the front bearing intercepted by two hardened steel washers.

The turret-head can be adjusted in position upon the machine and firmly clamped by the bolt *a* (*fig.* 4). As the turret slide *b* moves to the left, the turret *c* remains firmly locked in position, the forward motion of the turret slide being arrested by an adjustable stop-screw (*d*). By moving the slide to the right a locking-pin is withdrawn from a hole in the bottom of the turret by a lever upon which a heavy spring presses and holds the pin in the hole. As the slide moves to the right, the end of the lever rides under a steel piece, which is free to swing in the opposite direction and withdraws the pin from the turret. As the movement of the slide continues, a ratchet-pawl engages with a ratchet-wheel, and turns the turret, the pawl being brought to its neutral position by a coil-spring. Meanwhile, a projection upon the lever has passed from under the steel piece, and the spring is acting, so that as soon as the hole in the turret comes under the pin, the pin is forced in. At this instant the relative motion of the slide and slide-rest is arrested by the contact of two lugs, so that in rapid working there is no danger that the locking-pin will miss the hole.

The principal tool-holders used in the turret-head are shown in Figure 5. *A* is the "box-tool," which, containing two cutters—one for roughing and one for finishing—can easily be taken out and ground. The shape of the box-tool allows easy access for measuring the work. *B* is a die-holder, the die being held by three screws, which allow the die to be so adjusted as to swing concentrically with the spindle. The part *b'* fits freely upon *B* and is clamped in the turret. *C* is a tap-holder and works the same as the die-holder; *c* is for holding hollow mills and other tools,

and *d* is the stock, with which the rapidity of the wire-feed is gauged. Figure 6 (*pl.* 23) shows the cross-feed.

Drills and Drilling-machines.—To bore a cylindrical hole in wood or metal it suffices to place upon the material a pointed steel tool provided with scraping- or cutting-edges and to rotate it with a constant pressure in the direction of its axis. A tool of this kind is called a "drill." The forms of the cutting-edges vary greatly, according to the different materials to be drilled.

Metal Drills.—Of the drills for metals illustrated on Plate 24, Figures 1 and 2 represent straightway drills; Figure 3 a drill for boring brass and soft metals; Figure 4 a countersink; and Figure 5 a countersink and drill combined. Figure 6 shows the ordinary single-cutting drill, in which the point is nearly a rectangle formed by only two facets symmetrical to the axis. Drills of this kind, being liable to run out of centre, have been improved by increasing the length of the parallel portion next to the edges and by maintaining it at a width equal to the diameter of the bore (*fig.* 7). In the drill shown in Figure 8, which is intended for lathe use, there is a single edge on the end of a semi-cylinder, the central point, as in Figure 9, being wanting. The twist-drill (*fig.* 10) may be considered the most complete form for metals, continuous removal of shavings being effected through two helical channels.

Metal-drill Braces.—For manipulating drills the crank-brace (*fig.* 12) is mostly used. The "feed" of the drill is effected by a powerful screw, with a box in a horizontal arm of a frame connected to the material to be drilled. While the right hand moves the handle of the brace in a circle, the left effects gradual advance of the drill by a bar pushed through the head of the feed-screw. A suitable combination of crank-brace and ratchet-brace is shown in Figure 11. The brace does not receive a continuous rotation, but a pendulum-like oscillation, through which the advance of the drill by means of pawl, ratchet-wheel, and screw is automatically effected. Figures 14 and 15 represent ratchet-drills employed by engineers, machinists, bridge-builders, ship-builders, boiler-makers, etc. Figure 3 (*pl.* 26) exhibits a hand-drill which can be fastened to a work-bench or to the flange of a casting by means of a clamp and a stud, or can be permanently bolted to a bench or any flat surface. The post and arm are both round, and are held in split bearings, which allow the drills to be placed in any position and at any angle. The crank-handle, to suit the size of the hole being drilled, is adjustable, and it can be used either at the end of the arm (*B*) or at the end of the spindle (*A*).

Vertical Drilling-machines.—Drilling-machines are so arranged that of the two motions (rotation and rectilinear translation) to be imparted to the tool the first is derived from a transmitting shaft driven by power, while the other is effected either automatically or by the hand or the foot of a workman. Figure 13 (*pl.* 24) shows a vertical drilling-machine for metals, in which the material to be drilled is secured to a table which can be adjusted at any height desired. The drill, fixed in a vertical spindle,

receives its rectilinear motion by pressing down a treadle and its rotation by bevel-gear, from a revolving belt-driven shaft. The speed for every material has to be determined by experience, but to give different rates for drills of different diameters "stepped" or cone pulleys are provided. The drill-spindle, in order to acquire the motions to be imparted to it, passes through the hub of one of the bevel-gears, the latter being so connected to the frame that it can be turned, but not shifted vertically.

A vertical automatic drilling-machine is shown in Figure 17 (*pl.* 24). The drill-spindle is turned by a horizontal driving-shaft with cone pulleys, and a counter-shaft placed near the ceiling. By special gearing, consisting of two pairs of spur-wheels, the number of velocities can be increased to double the number of belts. Automatic advance of the drill is derived from the same driving-shaft by a belt-gearing (which can be run on three different pairs of pulleys, as seen on the right of the Figure), a horizontal counter-shaft, a worm-wheel gear, a vertical auxiliary shaft, a pair of spur-wheels, and a nut and spindle. The latter being connected with the frame for sliding and with the drill-spindle for rotating, the rotation communicated to the nut is changed into vertical sliding of the drill-spindle.

Some machines for drilling and boring give good examples of aggregate motions, the spindle carrying the cutting-tool turning rapidly and at the same time advancing slowly lengthwise. Suppose a screwed spindle to have upon it a spur-wheel and to bear a nut upon which there is a smaller spur-wheel; then, if these two spurs have different speeds, the spindle will not only turn, but will also advance lengthwise, and the rates of turning and advancing (or feeding) may be varied at will independently of each other. A self-acting drilling-machine which is not automatic turns the wheel attached to the nut by a power-driven bevel-wheel, while the wheel upon the spindle is worked through another one, upon a shaft having a wheel turned by hand at will. The drill-spindle has in its lower part a groove, and the inside of the tube, which bears the wheel giving the rotation, has in this groove a projection or feather, so that the spindle can move lengthwise, as though it were a part of the tube. In some machines a rack and a pinion take the place of the screwed spindle. The self-acting part consists of a small cone pulley, whose axis has a second endless screw and just over the end wheel a worm-wheel, which may be slid into gear, so that it can be turned by the driving-shaft. Bodmer's self-acting drilling-machine has a screw-thread upon the drill-spindle, while a projection upon the inside of the boss of the lower wheel fits into a groove, so that the spindle can pass through the wheel, although they must turn together. A pipe-like nut having a wheel at the bottom receives the spindle. One pinion brings the drill down to the work, the other raises it, and the fine feed is the result of the combination of these two rates. In Whitworth's friction-drill the spindle has two worm-wheels, embracing its screwed portion upon opposite sides. If not permitted to turn, they form a nut which causes the spindle to move lengthwise; if free to move,

the spindle will neither advance nor recede. The application of friction to retard them more or less makes the feed coarse or fine.

In the Elliott drill-press, shown in Figure 12 (*pl.* 25), the cone is hollow throughout and terminates in two sleeves, which constitute the journals upon which the cone revolves. Their bearings are of brass, made in two parts, and held in place after the manner of engine-lathes: the weight of the cone is taken upon a rawhide washer that rests upon the top of the lower brass bearing, which latter has a flange projecting upward around the washer, for the purpose of retaining the oil. The steel spindle, which carries the drill-chuck, passes through the sleeves, each of which forms for it a long bearing; the spindle is made to revolve with the cone by the driver, which is pinned to the spindle and whose ends embrace two rods, which form a part of the cone. Around the spindle and extending from the driver to the bottom of the cone is a steel spiral spring, which serves as a counterbalance to the spindle and chuck. Power to feed the drill is applied to a collar having a bearing directly over the chuck. The wear incidental to the thrust of feed-lever is taken by a rawhide washer. The lever, which is attached to the collar, is actuated by hand- or foot-levers through the medium of a rod inside the column; and when desired, the descent of the spindle may be accurately stopped at any given point by means of a clamp collar. The lower end of the hand-rod is connected with the inner arm of a segment, which is free between the forked ends of the hand-lever and foot-lever, either or both of which levers may be connected with the segment at any point by the insertion of pins. By loosening a set-screw the length of hand-lever may be changed to suit different workmen.

The Sensitive Drilling-machine, shown in Figure 5 (*pl.* 26), was designed with particular reference to the accomplishment of rapid and accurate work with small drills, and at the same time to obviate as far as possible all danger of their breakage. By small drills are meant drills from ⅜ of an inch in diameter, the size of an ordinary lead-pencil, down to .015 of an inch in diameter, the size of a cambric sewing-needle. One of the chief requisites of a drilling-machine for this purpose is a true- and light-running spindle. The usual mode of running a spindle is to attach a pulley to it direct and give it motion by a belting from another driven pulley. The objections to the old style were, first, the strain on the spindle by the belt tension, rendering it liable to spring; and secondly, the wear on the boxes or journals in which the spindle ran, occasioned by the strain and pull of the belt being always from one direction, with the consequent certainty of wearing the boxes out of round.

Through the top arm of the drill-frame (*fig.* 4) is inserted a hollow sleeve, whose lower end comes nearly flush with the frame—that is, it only extends through a sufficient length to provide a good bearing for the pulley to run on. The drill-spindle runs on the inside of this sleeve, and the pulley, with a hub somewhat longer than the upper end of the sleeve, on the outside. The spindle has a small groove or key-way cut lengthwise.

In the upper end of the pulley-hub a bushing is made fast, and in this bushing is the key fitting the spline in the spindle, which drives it when the pulley is revolved and at the same time provides for vertical spindle motion. Hence there is no belt tension on the spindle.

The next important point is in securing a feed of so sensitive a nature that the operator can at all times judge of the exact power applied and the resistance of the work to the drill-point. This feature is covered by balancing the weight of the spindle-chuck, etc., by a flat coiled spring. Through the lower or adjustable arm is run a pinion-shaft, whose pinion drives into a rack, which is in the form of a sleeve, in which the spindle runs, and is held in place vertically in the spindle by the nut and collars shown. On the outer end of the pinion-shaft is keyed a disc, into which the lever is set, while on the inside thereof is a projecting pin, over which is placed the end of a flat coiled spring. The spring is coiled in a spring box of the same diameter as the disc referred to, and to adjust the spring tension is arranged to revolve on a boss or projection on the frame. When the spring is so set that the tension thereon just balances the weight of the spindle, its attachment, lever, etc., the spring box is made fast by a set-screw to the frame, and the lightest touch on the lever will raise or lower the spindle. When in operation, the only resistance to the hand is that of the material being drilled, and the expert operator can force his drill up to its safety limit. By loosening a hand-nut on the back of the post the lower head can be set at any height, allowing for quick adjustment for varying thicknesses of work.

One more very essential feature in light drilling is that the tool shall run steady without vibration, especially about the spindle. A recent improvement makes the top arm in two pieces planed together, to slide on a tongue and groove, and provided with an adjusting screw and lock-nut. With this arrangement an endless leather belt can be used to drive from the spindle-driving pulley on the back cone to the spindle pulley, and thus do away not only with the vibration caused by the lacing running over the pulley at high speed, but also with the trouble and expense of lacings and the necessity of providing means for keeping the belt at the proper tension at all times. The drill-table swings around on the head of the column, so that the supplementary table underneath can be used, or by removing the latter stand a bell-shaped stand can be used in its place. The support for this lower table- and cup-stand is adjustable on a slide to any height. Drills having the essential good points of this one are made having two, three, four, and even more, spindles. The arrangement made for driving the two-, three-, and four-spindle drills with a single endless belt is a great convenience, doing away with the care required to keep up a short belt for each spindle.

Radial Drilling-machine.—As it frequently happens that several holes are to be drilled in the same direction in masses of metal which are heavy and difficult to move, the vertical drilling-machine is sometimes so arranged that within a certain range the drill-spindle can be shifted to every desired

place without detriment to the motion to be imparted to it from the driving-shaft. If this is attained by radially pushing the head containing the drill-spindle upon a horizontal arm and by rotating this arm, this kind of machine is called a "radial" drill (*pl.* 24, *fig.* 16). The arm rotates around a cast-iron column, having in its axis a vertical shaft, which receives at its lower end a rotation from the horizontal driving-shaft by a bevel-gear and transmits it on the upper end, by another bevel-gear, to a horizontal shaft (not plainly shown in the Figure), which participates in the motion of the arm as well as in the rectilinear displacement of the drill-spindle carriage. This shaft being connected (by spline and groove) with the bevel-gear driving the drill-spindle, the connection of movement between the driving-shaft and drill-spindle remains the same for all possible positions of the drill. The drill-feed motion is derived from its rotation in the same manner as in the machine represented by Figure 17, except that here the feed can also be executed by hand by turning the hand-wheel, at the right of the drill-spindle. The material to be drilled is secured to the horizontal or vertical surface of the frame, which is provided with T-grooves, or, if very large and heavy, is placed directly upon the floor.

Single Vertical Drilling-machine with Combined Motor.—In the single-spindle drilling-machine, represented in Figure 1 (*pl.* 26), the working machine is combined with a motor, forming in this case a vertical drilling-machine with an oscillating steam-engine. Such a combination offers many advantages. The working machine being entirely independent of other machines, the uniformity of its running is not affected by nor does it disturb the others; power is used only while the machine is running, and portability, applicable in the construction of large materials—bridges, ship-hulls, etc.—is obtained by conducting the power (steam, water, or compressed air) from its source to the machine. A bevel-pinion upon the engine crank-shaft drives a large bevel-wheel, whose shaft carries the drill-bit. The feed is by hand, the vertical shaft upon the large bevel-wheel being hollow and internally threaded. This machine has its analogy in those mortising-machines for wood in which the mortise is made with straight sides, flat bottom, and semicircular ends by a rotating auger having a traverse at right angles to its axis, the ends being squared by a mortising-chisel after the auger-bit has done its work. With the metal-working cotter-drill, if it be desired to have square ends to the groove, they may be either chipped out with a hand-tool or squared by a slotting-tool. In the ordinary drill the work is held stationary, and the tool, whose axis is vertical, is given rotation, while its feed is only in the direction of its axis. In the cotter-drill the tool is given feed in the direction of its axis, and the work is also fed at right angles thereto.

Cotter Drilling-machines.—Figures 9, 10, and 11 (*pl.* 25) show an admirable general application of drilling-machines, in which, besides the two motions previously referred to, there is added a third—namely, a rectilinear translation of the material at right angles to the drill axis (*fig.* 9), or, with the material remaining stationary, the same motion is imparted

to the drill, drill-spindle, and appurtenances. Suppose the drill has penetrated the material to a certain depth and this forward-and-backward motion there takes place within certain limits, the drill being fed sidewise every time it is reversed; then, instead of a circular hole, the result will be a groove with semi-cylindrical ends. The ends of these drill-cut grooves can subsequently be readily made rectangular by means of a chisel. These machines form a transition from drilling- to milling-machines. The bits used for them are shown in Figures 1 to 5 (*pl.* 25). Figure 1 represents a double-pointed drill and Figure 2 a rose-bit. Figures 3 to 5 are reamers.

Boring- and Turning-mill.—In the boring-machine proper the work is stationary and the tool rotates about an axis coincident with that of the piece to be bored. The tool has at the same time a lengthwise motion parallel with that of the work being bored; and if taper or other non-cylindrical boring is done, the tool has also an in-and-out motion at right angles to the axis of rotation. In boring- and turning-mills the work rotates, the tools having practically the same motions as upon an ordinary lathe, except that in the lathe the axis of rotation is always horizontal and in the boring- and turning-mill it is generally vertical.

The boring- and turning-mill is now a necessary part of the outfit of any large machine-shop. The Niles type, shown in Figure 2 (*pl.* 26), is a leading example. There is a very heavy table, driven by spur-gearing and having a long massive spindle running in bearings adjustable for wear. For light work the table is carried only upon a steel step, but for heavy work the step is relieved and the table lowered upon an annular bearing under its outer edge. The driving-belt is at the side. The cross-rail, which carries the tool-heads, is raised and lowered by power. The tool-bars, which are counterbalanced by weights, can work at any angle, can be operated from the end of the rail by hand, together or independently, and can also be worked at the saddles by a quick hand movement, while the feeds are automatic in every direction, and also variable in very great degree. The right-hand saddle has quick traversing movement by hand in addition to a slow hand movement and the feed. Besides boring and turning, this mill, by an attachment, can without clamping do pulley-turning on a mandrel, slotting and key-seating, cylinder-boring, thread-cutting in large valves, grooving in hoisting-apparatus, drums, etc.

Planer-tools.—The tools for planing metals (*pl.* 25, *figs.* 6–8) are of larger dimensions than those for wood and have a greater cutting-angle, corresponding to the greater resistance of the material. They usually have a convex edge or an angular cutting-point, and consist either of a single piece of steel (*fig.* 8) or of a short piece set in an iron holder (*figs.* 6, 7). These tools are used only in machines applied to metal-planing.

Though nearly all the machines for working wood, and commonly called "planing" machines, are substitutes for the hand-plane, they are actually cutting-machines, since they work with revolving tools. Metal-planing machines may be divided, according to the direction in which the separate cuts are executed, into vertical and horizontal, and the latter may be

divided into planing-machines with movable irons and those with stationary irons.

Horizontal Planing-machines.—Most of the planing work upon metal, as upon wood, is done in a horizontal direction. In small work the material is held still and the tool is given a comparatively slow working-stroke and quick return, the feed being effected after the working-stroke is completed. Such machines are termed "shapers."

For large work, by some strange inconsistency, the piece to be operated upon is given horizontal movement for the working-stroke while the tool is held still, the feed for the new cut being effected after the working-stroke is made, and the return or idle stroke being comparatively rapid.

The Horizontal Planing-machine with Stationary Tools, represented in Figure 5 (*pl.* 27), holds the tool in a support, which allows it to be placed obliquely and to be shifted vertically. The support itself can be shifted upon a horizontal prism extending the whole width of the machine. A slight lateral feed (generally also a shifting in the vertical sense) can thus be imparted to the tool by a special mechanism after each cut. The piece of metal is secured by suitable screws, stays, etc., to a cast-iron table, which can be horizontally shifted upon a long and strong cast-iron bed by a partially-executed prismatic guide. Upon the under side of the table is a rack, which meshes with a gear upon a horizontal shaft and receives a back-and-forward motion from the driving-shaft. Thus it will be seen how after suitably setting the tool the surface of the piece of metal can be smoothly planed. To get sufficient space for working articles of some height the horizontal prism carrying the support is so arranged that it can be vertically shifted on the front side of two cast-iron uprights screwed or cast to the above-mentioned cast-iron bed and connected at the top by a cross-piece. The support is raised or lowered by two vertical screws of equal pitch, which can be turned simultaneously and at the same speed by a horizontal shaft above the uprights. Fastened on the side of the table, at a distance from each other corresponding to the length of the piece of metal, are two tappets, which by striking against a short lever reverse the table motion at the proper time and simultaneously effect the lateral shifting of the tool-bit.

Whitworth Planer.—To effect its reverse motion the Whitworth planer has a combination of three pulleys with three bevel-wheels. There are upon one shaft three pulleys, the central one of which is idle and rides loose; the outer pulley is keyed to a shaft ending in a bevel-wheel, and the pulley at the inner end of the set fits upon a pipe, through which the shaft passes, and upon which is a bevel-wheel with its teeth pointing toward the first bevel-wheel. At the end of the shaft, which is to be reversed, is a bevel-wheel, which engages with both the other bevel-wheels. When the belt is shifted from the inner to the outer one of the three pulleys, the shaft is reversed; if kept upon the middle pulley, there is no motion. The objection to this arrangement is that the motion is at the same speed in each direction, necessitating a reversing-tool or "jack in the

box." This is worked upon the same principle as the hand-drills, in which the rotation is effected by pushing a nut up and down a rod, upon which there is formed a screw of rapid pitch, so as to cause the spindle to rotate first in one and then in the other direction as the nut rises and falls.

The Sellers Planing-machine, shown on Plate 28 (*fig.* 1), has its reciprocating motion given by spiral gearing without the intervention of bevel-wheels, the intention being to obviate the chatter-marks caused by other kinds of gearing. The reciprocating motion is not produced by shifting belts, but by friction clutches, and the driving and shifting are so positive that the machine will plane to a shoulder. The table has one plane and one flat angular way, the latter having four bearing-surfaces, two to carry the weight and two to take the side-thrust. The table is guided laterally by two surfaces, both nearly vertical. The feed is distinct from the motion of the table and is driven positively from a slow-running pulley by an ingenious appliance for transmitting and arresting motion. It is caused by adjustable stops on the table, and takes place while the machine is reversing, and at the end of the back stroke if desired, no matter in which direction the feed is working. The machine is operated from either side by levers that control the table motion and can at will at the same time cut loose and arrest the feed, so that the table can be run past the stops as often as required for examination or adjustment of the work. The cross-head, which incloses the saddles, takes up the wear. On planers of 36 by 36 inches, and larger, when fitted with two saddles on one cross-head, the feed-screws and rods to each are separate, so that each can be operated in all respects independently except in the amount of feed, which will be the same for both saddles; the amount of feed to each saddle can also be made independent. The feed is adjustable, from one whole revolution of the feed-screws down to nothing, by an infinite gradation, there being no teeth in the feed-ratchet to limit the changes. Planers 25 by 25 inches, and larger, are fitted with a tool-lifter, raising both tools on the back stroke, no matter in which angle the planing-tool may be advancing. The tools of both vertical slides stand in line with the main tools, are operated by separate feed, and can be lowered below the top of the table when not in use. For the cross-head large planers have lifting machinery operated by friction-wheels, which can be held to their work without much effort, but which, to avoid accidents, stop as soon as the workman releases his hold on the lever. Machines up to 54 by 54 inches, inclusive, have a return speed eight times greater than the speed of cut, or about 150 feet per minute. Machines of 60 inches, and larger, have a return speed six times greater than the speed of cut, or about 110 feet per minute. Machines of the latter class stand parallel with the line-shaft, economizing room in the shop, and, having no shifting-belts from the counter-shaft, the position of the latter is not so limited as on old styles.

The Open-side Planer differs from the ordinary type in having one side entirely open, so that very wide work may be taken in. The plate-planer

is for planing straight and smooth and bevelling the edges of boiler- and bridge-plates of wrought iron. The rotary planer is practically not a "planer," but a gigantic milling-machine with cutters having adjustable teeth. In the pit-planer, which was once used for very heavy work, the material is held stationary and the tool is given traverse, as in a shaper, so that we find the motion given to the tool for both the lightest and the heaviest work—an apparent inconsistency.

Shapers.—Horizontal metal-planing machines with moving tools and stationary work, also called "shaping-machines" or "shapers," are represented by Figures 3 and 4 (*pl.* 27). The head, carrying on the front end a special tool, receives alternating motion in a horizontal guide by a mechanism similar to that for vertical machines. The piece is secured to a bracket-like table, which is step by step pushed forward horizontally by a rack and pinion (*fig.* 4). Sometimes the table is stationary and the lateral position of the portion containing the guide is attained by a rack and pinion and a screw (*fig.* 3), the result in both cases being the execution of a level plane on the piece of metal. By securing the latter to a horizontal spindle (between two cones) and imparting a step-by-step rotation, a cylindrical surface will result. This manner of shaping cylindrical surfaces is suitable where they are not to be made over the entire circumference of the piece, and hence cannot be made in a lathe.

Vertical Metal-planing Machines (generally called "slotters," or "slotting-machines").—The arrangement of vertical metal-planing machines is illustrated in Figures 1 and 2. The tool is on the lower end of a vertically guided carriage, which receives an up-and-down motion by a crank and pitman from a driving-shaft provided with a cone pulley or by intermediate wheels and crank-gearing. The piece to be worked (in Figure 1 a spur-wheel, whose hub is to be provided with a key-groove) is secured to a horizontal table provided with planed grooves. This table can be revolved around a vertical axis as well as pushed in two horizontal directions crossing each other at a right angle. These three motions can be executed either by hand (by turning three cranks) or by suitable mechanism from the driving-shaft. Hence, after each cut the piece can be so placed that the resulting surfaces make up a level or a surface belonging to the ordinary surfaces of a cylinder. With such a machine it is, for instance, possible completely to finish to a scribed line the clearance spaces between the teeth of a spur-wheel. By arranging the table (*fig.* 6) so that its upper portion can be placed obliquely, conical shapes can be completely finished.

Milling-machines are so constructed that while the tool rotates the work has a traversing motion, and often, in addition, an intermittent partial rotation about its own axis, or a cross-feed, so as to bring new portions under the action of the rotating cutters.

Universal Milling-machines (*pl.* 28, *fig.* 2) are termed "universal" from their almost unlimited variety of operations. With rotary cutters they in many instances do more accurate and expeditious work than the

planer or shaper, and they also turn, bore, drill, and flute taps and reamers, and cut gears and spirals. They have all the movements of the plain milling-machines, and, in addition, the table is fed automatically at any angle to the axis of the spindle. The spiral head is so made and connected with the feed-screw that a positive rotary movement may be given to the work, and by index mechanism the periphery of the work may be divided into an equal number of parts. The knee can be moved vertically and the saddle holding the spiral bed can be moved parallel with the axis of the main spindle. Motion is transmitted from the feed-cone through a feed-shaft to a bevel-gear and clutch at the end of the bed. If it is desirable to employ this feed when cutting a left-hand spiral or at any time when there is considerable distance between the end of the bed and the feed-cone, the shaft is lengthened with an extension-rod. A series of graduations shows the angle to the axis of the spindle at which the table is fed, and index-dials record the vertical and horizontal knee movements in thousandths of an inch. Motion is communicated from the feed-screw to the spindle of the spiral head through change-gears, bevel-gears, and a worm and worm-wheel. The change-gears regulate the rotary movement of the spindle, or of the work, relative to the speed of the feed-screw, and any spiral of the sixty-eight provided for may be cut without interfering with the divisions obtainable from the index-plate on the spiral head. The spindle may be given any portion of a revolution or may be rotated continuously. There runs through it a taper hole, which receives the collets and arbors used in the main spindle. The front end of the spindle is fitted to receive a chuck. The worm-wheel is so made that it may be adjusted to compensate for wear. The worm-shaft runs in steel bushings, which also serve as a spindle-box pivot. The front end of this box may be elevated or depressed, so that the spindle can be set at any angle from vertical to 5° below horizontal. Every intervening point is indicated by graduations on one of the upright sides of the spiral head, and the head may be held by a clamp-bolt and the spindle left to revolve. A turn of the worm-shaft moves the work or spindle $\frac{1}{40}$ of a revolution; hence, by use of the index-plate, a turn of the worm-shaft may be subdivided into various parts. The necessity of counting the holes when dividing the work is obviated by using a sector in connection with the index-plate. By the raising-block the spiral head may be set at any angle on the bed. The vise-base is round and can be clamped upon the bed at any angle. This machine is also constructed with an overhanging arm, to support the outer end of the arbor carrying the cutter.

The Milling-tool may be regarded as a great advance upon the grindstone, and, for certain purposes, as greatly superior to the emery- and corundum-wheels, particularly for removing unnecessary masses of metal and for bringing pieces down to a desired profile. It may be considered as a rotating planer or shaper-tool. By its use the cheap and rapid production of desired profiles may be effected by power with great uniformity and perfection of result. Its cut is usually in straight lines; as a general rule, the

object to be milled is not rotated. In some machines the cutters have only a rotating movement and the work is fed to them in straight lines; in others the cutter has a traverse and the work remains fixed; while in some machines both the cutter and the work are fed. The metal-milling machine finds its high-speed counterpart in the planing, matching, moulding, and tenoning wood-working machines employing cutters upon a rapidly rotating shaft, the blades having a working length equal to, or greater than, the width of the surface to be removed, and their profiles effectively corresponding to the outline of surface to be produced. The milling-cutter as sometimes used is akin to the rotating drill; again it resembles in its operation and product the routing-machine. Countersinking-machines show good examples of both such resemblances, some of them working both with the cylindrical periphery and with the end of the rotating cutter-bit. Milling-cutters are either solid—in which case they always lose their size as they are worn by work and sharpening (sometimes losing in effectiveness or working diameter and thickness for the same reason)—or have their cutting-edges so disposed with regard to the mass and the cutter, and with reference to the body to be worked, that even as they are ground down they make the same size and profile of cut. The latter is a most desirable feature, and exists nowhere in greater perfection and to greater advantage than in cutters for working out the spaces between the teeth of gear-wheels.

Milling Operations.—Figures 1 to 24 (*pl.* 29), which the following explanation will enable the reader to understand fully, are exceedingly interesting. Figure 1 shows how hexagon nuts or heads of bolts are milled with a single cutter; Figure 2, how a number of nuts while strung on a mandrel are milled at one time with two cutters; Figure 3, how a number of caps are milled, and how at the same time their sides and bottoms are accurately finished; Figure 4, how a T-slot is milled having a groove milled or planed to the proper depth; Figure 5, how a V-slot is milled; and Figure 6, how the guides of a housing are milled. This can be done with a cutter the width of the guide or with a saw about ¼ inch thick, finishing one side and then the other. A small cutter should then be applied to finish the inside bearings. The housing requires but one chucking. Figure 7 shows how to turn out a hole with a boring-bar arbor. Various work can be drilled and bored out to advantage in this way, either by bolting the work on the table, by gripping it in a vise, or by holding it between centres. Figure 8 shows how to mill a key-seat in a vise or between centres; Figure 9, how to mill a taper-reamer; Figure 10, how to cut a number of gear-wheels when strung on a mandrel; Figure 11, how to mill a tap; and Figure 12, how to hob a worm-wheel after the teeth are cut. The latter operation gives the teeth the proper shape, so that the shafts will stand at right angles to each other. Figure 13 shows how to cut off pieces of metal, and Figure 14 how to mill a thread-chasing tool, the milling-cutter to be V-shaped and at an angle of 60°. First one side and then the other can be milled without re-chucking. Figure 15 shows how to mill an

angle, finishing, at the same time, the sides and bottoms; Figure 16, how to mill a slot with a small cutter; Figure 17, how to mill a fork true with its round shank, one end being held in a universal chuck, which is screwed on the spindle of the indexing centre, and the other in a steady-rest; Figure 18, how to cut a rack; Figure 19, how to mill boxes perfectly true with the hole; Figure 20, how to mill an angular cutter; Figure 21, how to index dial-plates, the tool not revolving; Figure 22, how to mill a cam; and Figure 23, how to mill a friezing-bit for wood-work. First the sections are milled out with a square-faced cutter, and then the cutting-edges are milled by placing a right-and-left angular cutter on the milling-arbor. These bits can be milled complete before removing them from the mandrel. Figure 24 shows how to cut off round or square stock by placing the universal chuck on the main spindle and using the overhanging arm for a length-gauge.

The Automatic Gear-cutter, shown in Figure 8 (*pl.* 23), is used for automatically cutting or milling teeth upon the periphery of blank wheels for cog-wheels, or, as they are more properly termed, gear-wheels. To cut gears it was formerly necessary, when the means of the manufacturer were limited, for the operator to put in his entire time at the machine, since, after having the blank wheel and cutter in position, he had to feed the cutter through by hand, withdraw it, and then give the divisions on worm-gear or dial, repeating this operation as each tooth was cut on the wheel. With the gear-cutters known as "half-automatic" the operator goes through the same work, with the exception that the cutter feeds itself through the wheel and then stops. The workman then withdraws the cutter, gives the required divisions by hand, sets the self-feed, and then proceeds, repeating the operation for each tooth on the wheel. Nearly his whole time and attention must be given to this machine when in operation, because it feeds the cutter only through the teeth.

With the automatic gear-cutter the workman can without attention cut either bevel-, spur-, worm-, or face-gears, and after the machine has been set and started it can be run at a slight expense. He sets the blank to be cut, adjusts the machine and starts it running, and then can go about other work and let the machine take care of itself. The machine feeds the cutter through the wheel, draws out the cutter, and makes every change or division of the worm-wheel itself. It makes the divisions with perfect accuracy, the dividing-disc making only one revolution for any number of teeth; and when properly set, mistakes are impossible. In a hand-machine mistakes are liable to, and often do, occur. When done cutting a wheel, the machine strikes a gong, thus notifying the workman to come and put in another blank. It is constructed of the following principal parts. The main frame is in the shape of the letter L, upon the front face of the vertical portion of which are two V-tracks, placed for the alignment of a vertically movable head, which contains the barrel and spindle for holding the work, this spindle or work-mandrel being inside the barrel. To the outer or rear end of this barrel is fastened a worm dividing- or

master-wheel. Alongside this master-wheel, but fastened to the movable head, is suspended a back or frame. The worm-shaft, engaging with the master-wheel, is supported from this back, as are also the bracket for placing the various combinations of change-wheels for dividing purposes and a one-revolution stop-shaft cam and trip. To the end of the worm-shaft, opposite to the end on which the change-wheels are placed, is a slipping friction-wheel, which is driven from the counter-shaft, and which has a tendency to cause the shaft to revolve; but it is kept from doing so by the stop-shaft cam. This worm-shaft is permitted to revolve only for dividing purposes. The entire movable head and parts attached are raised and lowered by a screw with a hand-wheel, which is graduated for accurate adjustment. The cutter is driven by a counter-shaft with a three- or four-step cone pulley, belted to a cone-stand on the floor, motion being given to the train of gearing driving the cutters by two universal joints with a slipping sleeve. This sleeve enables the cutter-slide to be placed in any position for either bevel- or worm-gears without affecting the length of the belts. For moving the cutter-slide in and out, motion is brought to its front part by means of a V-belt or light train of gearing from the train-driving cutter-arbor. The in-and-out motion is obtained by two clutches, one for feeding, which revolves at a slow speed, the return motion being much quicker. These clutches run loose upon the shaft, but between them is a single clutch, which has teeth on each side, and which slides back and forth between the opposite running clutches on a key or feather, fastened in the same shaft. Thus, as this central clutch is made to engage with one or the other of the clutches, a back or a forward motion is imparted to the feathered shaft, which is connected to the screw operating the cutter-slide.

The central clutch is automatically controlled by a system of levers and two adjustable buttons with opposite bevelled faces attached to the lower stationary slide, the levers and rollers being attached to the movable slide above. As the roller touches the bevelled button it throws the lever to one side, shifting the clutch and reversing the motion of the slide. When the roller comes to the oppositely bevelled button, the clutch is thrown to the opposite side and the motion is reversed as before. Means are provided to stop the feed at any desired point. There is a connection by a light chain between the cutter-slide and the stop-shaft cam and the trip. When the slide is withdrawing the cutter and the latter is out far enough to clear the edges of the blank wheel, the chain (which is adjustable) pulls the trip and allows the stop-shaft to make a revolution, then holds it stationary until another tooth is finished, when the slide again withdraws, releases the trip again, and so on until the wheel is completely cut, when the machine rings a bell, notifying the operator that the wheel is complete. The working movements for cutting bevel-gears are the same as those described, the slides being raised to whatever incline is desired. For worm-gearing the slides are swivelled right or left, as required, in a horizontal position.

Shears and Punching-machines.—Figure 1 (*pl.* 30) illustrates the manner in which metal shears operate, *a* representing a piece of sheet iron and s^1 and s^2 two chisel-like tools (shear-blades), which are so forcibly moved toward each other that the edges penetrate and divide the iron. By giving to one blade the form of a ring (*fig.* 2) and to the other that of a punch (*s* fitting into *r*) the shears become a punch and die, and the cut is circular. Shears are extensively used for trimming the edges of iron plates and sheets, while punching-machines serve for quickly making bolt- and rivet-holes, and also for working out irregular cuts.

In the ordinary cutting-pliers, which may be considered as precursors of shears, the two chisel-like blades do not move one past the other, and, as it is possible to bring only the edges in contact, the resulting cut surface is often somewhat uneven. In the nippers shown in Figure 5 the ordinary form is so far improved that by an adjusting-screw placed in one of the jaws the other jaw can be advanced only sufficiently to bring the edges almost in contact, thus preventing injury to the jaws.

Shears generally have straight cutting-blades acting by rectilinear displacement (parallel shears, *pl.* 30, *fig.* 4; *pl.* 31, *figs.* 4, 5; *pl.* 32, *figs.* 1, 2) or by rotation (lever shears). In the latter class two different arrangements can be made by the axis either running parallel or standing vertically to the blades. For executing long cuts without interruption the blades are given the shape of circular discs, with edges sliding over each other. Such rotary or circular shears are shown in Figure 1 (*pl.* 31), in which both cutting-discs have positive motion. The blades are borne by two parallel shafts revolving in opposite directions, so that a piece of sheet iron—which must, however, not be too thick—introduced upon one side of the blades is delivered in two pieces upon the other side. That the iron be caught with requisite firmness the diameter of the blade must be at least eighty times the thickness of the sheet, so that, on account of the difficulty of constructing large steel discs, the application of this machine-shear (which otherwise is mechanically complete) is limited to cutting thin sheets. Double-lever shears are shown in Figure 2. The two movable blades are screwed to a large trapeziform casting, which oscillates upon a bolt in the centre of the frame and receives on its upper end its motion by a circular eccentric working in a vertical slot. This eccentric is borne on a horizontal shaft, and by means of a pair of spur-wheels receives its motion from the fly-wheel shaft of a small steam-engine.

Figure 6 (*pl.* 30) represents a punching-machine combined with a lever shear. *A* is the fixed blade of the shear, *B* the movable blade, *C* the punch, and *D* the die; *a* represents the rotating axis of the lever *b*, with which the movable blade of the shear as well as the punch is connected. The rotating axis bears on its outer end a pulley (*c*), upon which acts a heart-wheel (*d*) that vibrates the lever *b*. The heart-wheel (*d*) receives a slow rotation from a driving-shaft by means of gear-wheels (*e*, *f*). Upon this shaft, besides the fly-wheel *g*, are the fast and loose pulleys h^1, h^2, upon which the belt runs. The objection to such lever

shears is that with straight-cutting blades the angle under which the edges catch the material to be cut is variable and at first may readily be so large as to cause the material to be displaced by the blades. The punch C is shiftable in a prismatic guide (K) of the frame, and is moved downward by the short elongation of the lever b over a and upward by two drawing-rods (i) so attached that they can be turned to both sides of the lever-head.

Figure 3 (*pl.* 31) shows another combination of lever shear and punching-machine (De Bergue's). The movable shear-blade and the punch are, in a manner similar to that shown in Figure 2, secured to a trapeziform casting, which can be rotated about a horizontal axis and receives on its upper end a vibrating motion by means of a circular eccentric. This eccentric is keyed upon a hollow shaft enclosing the driving-shaft and receives a slow rotation by two pairs of gear-wheels. The fly-wheel shaft bears the driven pulley and gears through a pinion with the spur-gear shown in the front. This in turn drives the spur-gear which (shown at the back) vibrates the lever operating the shear and the punch.

An equally good representative of the parallel type is Whitworth's large bar-iron shear (*fig.* 4, *pl.* 30). A is the stationary lower blade, secured to a projection of the frame, and B the movable vertical blade, screwed to a carriage, which can be shifted in the prismatic guide a. The carriage is pushed up and down by the rod b from an eccentric on the front end of a horizontal shaft placed in the frame at c. The back end of this shaft carries a large spur-wheel (d) meshing into a smaller one (e) upon the fly-wheel shaft of a special engine (k). This fly-wheel is designated by f and the crank by g; h represents the slide-rod, i the piston-rod, k the steam-cylinder, l the sliding eccentric, m the eccentric-rod, n the valve-chest, and o the steam-admission steam-valve, which can be opened and shut by the hand-wheel p. These shears are intended for use in rolling-mills, for cutting rolled puddle-bars into pieces for "piling" or reheating. On account of the varying resistance in cutting such bars, and to prevent disturbance in the working of other machines, it is advantageous to use a separate motor for working the shear.

The large shears for sheet iron shown on Plate 31 (*figs.* 4, 5) are distinguished by the great length of the blades, by the use of which the edges of large plates can be trimmed at a single cut. For machines of this class a separate motor is usually provided. A special arrangement, shown in Figure 4, serves for quickly stopping the movable blade without stopping the engine and waiting for the heavy rotating masses to come to a standstill.

Figures 1 and 2 (*pl.* 32) show two frequently-used combinations of parallel shears and punching-machines, one transportable, the other stationary. In Figure 2 the shear and the punch are placed one over the other and in Figure 1 opposite each other, while both are belt-driven. In Figure 1 the power applied to the live pulley c^2 is transmitted through the pinion d to a spur-wheel (e), upon whose shaft is a second pinion (b),

which in turn drives the large spur-wheel *a*. The shaft of this wheel drives the punch *D* and the shear-blade *B*; the fly-wheel *f* is to aid the belt in overcoming the resistance of the material to be punched or sheared. The frame is a hollow casting. Figure 2 (*pl.* 32), which is a German portable punching- and shearing-machine, may be operated by belt- or hand-power. The same sliding piece carries at its lower end the punch and at its upper end the movable shear-blade. This machine has a truss frame.

Hydraulic Punch.—In the hydraulic-machine (*pl.* 30, *fig.* 3) the cutting-stroke of the punch is effected by a small force-pump (concealed in the framework and controlled by the upper hand-lever), conveying water or oil from a reservoir into a cylinder with its piston forming one piece with the punch. The up-stroke is effected, with the assistance of the lower hand-lever, after communication has been established between the cylinder and the reservoir. This arrangement is practically a combination hydraulic-press and punch. Shears may be classed as well under "Presses" as under any other head, as they operate by simple pressure.

Metal-working Presses are machines that do their work by pressure, which, whether exerted gradually or instantaneously, has the same effect as regards the energy applied, although sometimes, on account of the inertia of the material, there is an unequal distribution of that energy. The blacksmith's hammer as it shapes the iron on the anvil (*pl.* 32, *fig.* 3) is a primitive form of press; but if a pair of upright guides were attached to the anvil, restricting the hammer to a vertical motion, it would approach more nearly to the machine generally known as a press, and, in fact, would represent a class called "drop-presses" (*fig.* 4). While there are numerous styles of presses adapted for punching, shearing, and forming sheet- or bar-metal and other materials, they all contain the parts represented by the anvil or "bed," the hammer or "ram," and the guides or "slide-bearings." The bed and the slide-bearings are always at right angles to each other, and usually form part of the same casting, called the "frame."

Drop-press.—In a drop-press (*fig.* 4) the ram, after being lifted to a certain height, is allowed to descend by gravity, the amount of work produced depending on the height of the fall and the weight of the ram. In doing work which requires sudden pressure, such as is given by a sledge-hammer, the drop-press or its equivalent is indispensable, but in most cases gradual pressure is required.

Power-presses.—In a "power-press" this gradual pressure is usually obtained by using a fly-wheel connected with the ram by an intervening shaft, crank, and pitman (*fig.* 5), and in a foot-press it is got by the intervention of a series of levers and their connections between the foot and the ram (*fig.* 7). In most power-presses the fly-wheel revolves loosely on the shaft, to which motion is given—only when connected with the wheel—by a "clutch," which device is generally a pin that slides in a projection on the shaft and is capable of being moved out by a spring until it engages with a notch in the hub of the wheel. Most clutches are

"tripped," or caused to engage with the revolving wheel, by a treadle and a rod connected to a wedge or other device which by the action of the press itself has previously locked the clutch-pin out of gear with the wheel. The depression of the treadle unlocks this device and allows the pin to re-enter the wheel for another stroke. Press-clutches are usually thus made automatic—that is, they are so constructed as to throw the fly-wheel "out of gear" with the shaft at the completion of one revolution of the wheel, and the consequent completion of a stroke of the press. The clutch being operated by a treadle, the operator's hands are left free to handle the work.

The usual method of obtaining rectilinear ram motion from rotary shaft motion is by means of a crank or an eccentric on the shaft, which revolves in the head of a pitman connected with the ram. An advantage of this form is that the eccentric not only forces the ram down, but also draws it up, ready for another stroke. The amount of stroke (or distance the ram is caused to move) will, of course, depend on the amount of the eccentricity. The same effect may be produced by cams on the shaft bearing against rollers on the top of the ram, the ram being forced away from the shaft by the cams and drawn back to its original position by other means, such as springs, weights, or return-cams.

Toggle Coining-press.—When a small amount of motion and a consequent increase of pressure are desirable, the rectilinear motion can be produced by a toggle, which, on account of the nearly irresistible pressure exerted at the end of the stroke just when such a pressure is most required, is almost universally employed for coining-presses. Such a toggle is usually opened and closed by a crank motion. Coining-presses (*pl.* 33, *fig.* 1) usually have two massive columns, joined at the bottom by the bed and at the top by a trussed cross-beam, the columns being as close together as practicable, in order to get as much rigidity as possible.

Screw-press.—The principle of the screw is frequently used in presses to transform rotary into rectilinear motion. In this type the nut in which the screw works is a part of the frame, the end of the screw bearing against the ram (*pl.* 32, *fig.* 6). This is also an effective form of press for certain kinds of work, but it is now rarely used except for hand-power.

Drawing- and Punching-presses.—The shape and size of a press depend on the work for which it is designed. A press for cutting out large sheet-metal blanks, such as sections of "pieced" tinware, requires a well-spread-out frame with a large bed, containing a hole of generous proportions, through which may drop the sections cut in the dies (*fig.* 8). On the contrary, a press for punching out nuts (*pl.* 32, *fig.* 9), for shearing heavy bar-iron, or for other work which requires a heavy stress in a small space, must be compact, with a large reserve of metal in the frame, not only to withstand a breaking strain, but also to prevent any flexure of the parts, or, as it is called, "springing." Even if a press which springs open appreciably at every stroke should produce good work for a time, disintegration at the weakest point gradually goes on and will sooner or later make trouble.

For this reason, if for no other, a properly proportioned press-frame, with interior angles well filleted and with exterior angles neatly rounded, is always to be preferred, even if considerations of beauty are left out of the question. Presses for long and narrow work, such as buggy-axles, should have two or more pitmans to transmit the power from the rotating shaft to the ram. Where there are only two pitmans they should be placed near the upright columns, to obviate springing in the shaft, and the ram and the bed should be well trussed, to prevent springing. Presses for work that is cut and formed or formed only, such as tea-trays, fruit-can tops and bottoms, etc., are usually inclinable, so that the work pressed to shape in the dies may be raised out of the lower die by spring knock-outs, and be allowed to slide back by gravity through an opening in the back of the press. A style of press usually adopted for heavy punching and shearing has the shaft running from front to back, the front end of the shaft being turned into a crank-pin, while the fly-wheel is at the back, out of the way (*pl.* 32, *fig.* 9). For work in comparatively thin sheet-metals the form having the shaft running from side to side is preferred (*pl.* 32, *figs.* 7–9; *pl.* 33, *fig.* 2).

The "Bottom-slide" Press (*fig.* 4) possesses several advantages. It has a heavy base supporting the shaft or shafts, gearing, fly-wheel, etc., while columns of considerable tensile strength support a trussed head. The ram is guided by the columns, is given an upward motion by cams on the shaft, and returns by its own weight, thus obviating the necessity of an expensive lifting arrangement. This press is adapted for deep drawn-work. It economizes metal, which is massed in and around the base of the machine.

Although the ram is made in many forms, its adjustment, which is an important feature, usually depends on the screw principle in some shape, but eccentrics, wedges, and other devices are also used. In some presses the bed is capable of adjustment, by which considerable latitude is possible between the bed and the ram; but this often affects the rigidity and accuracy of the press. The complexity of presses increases in accordance with the increase of the complexity of the work to be produced. Deep or drawn work, such as seamless cups and pans, not only is cut out but also is drawn to shape by a single stroke of a double-action press. Such presses contain two rams, one inside the other, so arranged that when the work of one is completed it is taken up and finished by the other. Triple presses are also in use. By multiplying the cams on the press-shaft the number of operations possible in a single revolution of the shaft is also multiplied.

The variety of articles produced in presses and dies is constantly increasing. The cheapness of household utensils testifies to the value of the machines by which they are made. Sheet-metal vessels, bells, lamps, and fancy goods of all descriptions, are sold at prices so close to the value of the raw material that the casual observer is at a loss to understand how they can be made for the money. To illustrate the almost boundless capacity of this class of machines it may be mentioned that a press fitted with gang-dies and operated by one man will cut and draw to shape in ten hours

two hundred and eighty thousand brass cartridge-cups and will turn out lamp-burner caps nearly as fast. The user of such articles has his wonder at their apparent cheapness turned to indignation when he learns that the retail vender asks a price so much above their first cost.

Power-hammers, while not usually classed among machine-tools or metal-working machinery, bear a prominent part in the work of the modern machine-shop. They are used on masses of metal (generally malleable iron or steel, usually worked in a hot condition) for the purpose of increasing their density, changing their form, or improving their finish. By them pasty material is worked to close up its pores and to drive out the gases and the slag; they are employed to reduce large thick masses to comparatively thin plates, to build up several thicknesses into one block, to finish objects already roughed out by other hammers or by rolls, to bend and shape pieces to desired forms, and to weld together separate lengths and shapes. The weight of blow given by hammers varies from a few pounds to a hundred tons. The weight, or hammer proper (also called the tup, or the ram, and sometimes the monkey, when free), may be attached to a helve or to a piston-rod, or it may be raised and let go free, as in a pile-driver, and it may strike either "dead" or "cushioned" blows.

Helve-hammers.—The blows of helve-hammers simulate those given by a sledge wielded by the human arm, the helve giving an elasticity desirable in some kinds of work. This effect may be increased by the use of springs. The helve may be raised by a cam or by any other mechanical device permitting rapid release, or, as in Figure 5 (*pl.* 33), it may be worked by a crank, from whose control it never escapes.

Drop-hammer.—Between the drop-hammer and the drop-press there is little difference. One form (*fig.* 6) has the weight or hammer attached to the end of a wide board, which is raised by being gripped between two rapidly-revolving rollers, and is then released by the rollers being so far separated that they no longer act upon the board by friction. In another form the weight is raised by a rope wound up by friction rollers and then released.

Crank-hammer.—One form of crank-hammer (*fig.* 8) has between the cross-head (which is driven by a connecting-rod attached to a crank) and the weight a strong spring of leather bands, thus giving a cushioned blow.

Steam-hammers.—Some steam-hammers have the weight attached to the rod of a piston raised by live steam, which is allowed to exhaust freely, thus causing the piston and the hammer-head to drop by their own weight. In this type the blow may be "dead," or it may be cushioned by the exhaust being closed at a certain point, so that the steam is compressed in the lower end of the cylinder. In another type of steam-hammer the piston to which the hammer is attached not only is raised by steam, but also is driven down by the same agent, thus striking the work with a force due not only to the weight of the piston and the hammer-head, but also to the steam-pressure. The blow may be cushioned or not, at the will

of the operator, who can compress the exhaust at any point in the stroke. The anvil may be carried by the same frame as the rest of the machine, or, as is best in large sizes, may have a separate foundation.

For forging metal into irregular shapes, such as cranks, marine rudders, locomotive rocker-arms, and pedestal-frames, an extra long stroke is required. For axles, trunk-bars, engine-frames, and for stamping work in forms, there is needed an extra width at the height of the anvil. Small machines have single standards or uprights; large machines with a very heavy hammer and striking a very strong blow have double uprights, which may be divided, for convenience in working, either from the front or from the side. Figure 4 (*pl.* 33) shows a 350-pound hammer with a single standard; Figure 7, a 2¼-ton machine with double standard. For convenience in finishing work it is now customary to place the ram or "tup" (terms applied to the hammer-head) and the anvil diagonally in relation to the single upright. This diagonal position permits long frames to be handled freely in either direction.

When steam is taken on the top, the machine may also be used as a squeezer or vise for holding work in hand-swaging, etc. Small hammers are generally arranged not only to take steam on both sides of the piston, but also to work automatically any number of strokes. Very large machines do not usually work automatically. Some machines have a supplemental valve for throttling the exhaust below the piston, but permit free exhaust above the piston—an arrangement which enables the blow to be diminished in intensity without materially decreasing the rapidity of motion. It is an advantage to have the exhaust-nozzle, with the drip-pan, so arranged that there may be used a large exhaust-pipe detached from the valve and carried by the roof, thus giving an exhaust free from back pressure, and enabling the water from the condensed steam to be readily carried off from the drip-pan to any convenient place below.

The precision with which steam-hammers operate is no less wonderful than the wide range of force with which they may be made to work and the titanic energy which the greatest of them exert. Some hammers which are capable of striking a blow of from fifty to one hundred tons are so accurate in their adjustment that they may be made to crack a walnut or may be brought down, without breaking the delicate crystal, to within a small fraction of an inch above the face of a watch placed upon the anvil.

Tendencies in Metal-working Machinery.—The tendency of manufacturers of metal-working machinery in general, and machine-tools in particular, is in two lines, leading from the previous direction of thought and work. Two distinct classes of machines are becoming more and more common each year: special tools for effecting from one to twenty operations at a time upon one article, where such article is manufactured in large quantities, and what might be called "universal" machines, having a wide range of adjustment and being capable of doing many kinds of work. Of the universal machines, the boring- and turning-mill pre-

viously mentioned is a good type, an important variant being a machine which not only bores and turns the cylindrical surfaces of large cylinders, but also planes their flanges, faces-off their valve-seats, and drills bolt-holes in flanges and seats without removing the cylinder from the machine, and with little if any change of place while being worked. Such a machine has a wide range in the dimensions of cylinders which it takes in and in the arrangement of their parts; in this respect it differs greatly from the special machine proper, which is intended to take in one or more articles at a time, but permits of little if any variation in design, construction, dimension, or finish in the articles produced.

The modern machine-tool is an instrument of precision, and its work is characterized by its greatly increasing accuracy and finish. The increasing exactitude of lead-screws and index-plates, due to the loving and intelligent labors of a few master minds in machine-tool building, has induced an increasing degree of accuracy in all other machine-tools and in all machines built thereby; and the standard having been thus raised, the demand has gone out from machine-builders for a higher grade of workmanship in all their machine-tools and metal-working machinery, so that all along the line, from bloom-squeezer and steam-hammer to delicate milling-machine and gear-cutter, the grade has been improved. Thus do demand and supply, desire and its fulfilment, go hand in hand, opening and smoothing the way of human progress.

It is to be regretted that the wide range of operations and the wonderful accuracy of modern machine-tools have done so much to lower the standard of personal dexterity in mechanical manipulations. The milling-machine and the emery-wheel have nearly supplanted the wonderful skill once exercised by the file and the scraper. The machinist is lapsing into a specialist, able to operate but one class of machines and to do but one class of work, and the working force of the machine-shop has become merely an assemblage of machine-tenders. (R. G.)

III. TEXTILE MACHINERY.

Among the utilitarian arts which mark man's progress from a state of barbarism, there are none of greater antiquity than that of spinning and weaving. It appears, indeed, to have come into existence with the first dawnings of civilization. In the remains of the Lake-dwellers there have been found shuttles and plaited stuff made of flax (*pl.* 34, *fig.* 3), which took the place of woven goods. The Mound-builders of the Ohio Valley manufactured from some vegetable fibre a coarse cloth woven with a warp and filling whose threads were uniform in size and regularly spun. The ancient Egyptians prepared "vestments of fine linen" (Gen. xli. 42), as also of cotton, and in their production, as their native monuments show (*fig.* 2), men and women were alike employed. In Exodus (xxxv. 30) there is mention "of the weaver," and Isaiah (xix. 9) in his prophecy concerning the Egyptians says, "They that work in combed flax and they that weave cotton shall be ashamed." The staff of Goliath's spear was like "a weaver's beam" (1 Sam. xxii. 7), and Job (vii. 6) says, "My days are swifter than a weaver's shuttle." "Penelope's web" (*fig.* 1) was woven by a Grecian princess; the Latin *filia* (daughter) signifies "the spinner," and the German *Weib* (wife), "the weaver." In the Middle Ages these handicrafts were ennobled in the eyes of all the people, and a golden spindle was placed upon the grave of Luitgard, the daughter of Otto the Great, as a testimony of her diligence.

Everywhere for long centuries practically the same methods and appliances were employed in working textile fibres; the distaff, the spindle, with or without the wheel, and the hand-loom were busy the world over. The poet's idealistic description of one of the phases of home-life in Acadie might, with variations to suit different conditions and customs, have been appropriately applied to every community:

> "Matrons and maidens sat in snow white caps and in kirtles
> Scarlet and blue and green, with distaffs spinning the golden
> Flax for the gossiping looms, whose noisy shuttles within doors
> Mingled their sound with the whir of the wheels and the songs of the maidens."

These slow and laborious processes continued until near the close of the eighteenth century. Previous to that time the materials employed in the manufacture of textile fabrics were mainly linen and wool, neither of which admitted, upon the wheel (*fig.* 5) and the hand-loom (*fig.* 8), of any great complexity of structure. Between the years 1767 and 1800 three inventions—namely, the spinning-frame, the cotton-gin, and the Jacquard machine—brought into being an extended list of fabrics infinite in variety of pattern and texture.

The Spinning-jenny (*fig.* 9), invented by Hargreaves in 1767, was capable of spinning from twenty to thirty threads at once with no more labor than had previously been required to spin a single thread. But the thread spun by the jenny did not possess the firmness required for the warp; this latter was made of linen until Arkwright, in 1768, produced

the cotton-spinning frame (*pl.* 34, *fig.* 11), by which there could be spun a vast number of threads of any required firmness and hardness, and with such rapidity that the work of one man sufficed to produce what before had required the labor of more than one hundred. Crompton's "mule-jenny" (*fig.* 10), invented in 1775, is a combination of Hargreaves's jenny and of Arkwright's spinning-frame.

The Cotton-gin.—The invention of the spinning-frame greatly increased the demand for the supply of the cotton fibre, but this demand could never have been met had there not been invented a machine for expeditiously separating the fibre from the seeds, which, contained in every boll of cotton, cling to the fibre with such tenacity that the process of separating them by hand is very slow and tedious, a pound of green seed-cotton being all that one person can clean in a day. Though a rude machine called the "churka" had long been in use by the Chinese and the Hindus, and a similar one called the "manganello" had been employed by the Italians, no satisfactory results were attained until the invention of the cotton-gin by Eli Whitney in 1793. This machine (*pl.* 35, *fig.* 2) had a wonderful effect on the cultivation and manufacture of cotton, and rapidly increased its production and consumption. Though not suited to the long-stapled Sea-Island cotton, the ordinary Whitney gin is employed for cleaning the greater portion of the cotton grown in the Southern States. Its average daily capacity is about thirty-two hundred pounds.

Jacquard Machine.—Previous to the invention of the draw-loom and the Jacquard apparatus mechanical weaving of figured stuffs was confined to simple patterns. The Jacquard machine (*pl.* 44, *fig.* 13) takes its name from its inventor, Joseph Marie Jacquard (1752–1834), who in 1801 perfected the machine left by Jacques de Vaucanson (1709–1782). The principle of the Jacquard apparatus was first employed in 1725 by Bouchon, who used a band of pierced paper pressed by a hand-bar against a row of horizontal wires, so as to push forward those that happened to lie opposite the blank spaces, thus forming loops at the lower extremity of vertical wires in connection with a comb-like rack below. In 1728, Falcon substituted a chain of card-boards in place of the band of paper of Bouchon, and employed a square prism, known as the "cylinder." In 1745, Vaucanson dispensed with the cumbrous tail-cards of the draw-loom, and made the loom self-acting by placing the pierced paper or card-board upon the surface of a large perforated cylinder, which travelled backward and forward at each stroke and revolved through a small angle by ratchet-work. He also devised the rising and falling griffe, and thus produced a machine closely resembling the actual Jacquard. His machine, however, remained incomplete and lacked the simplicity requisite for general use. In 1801, Jacquard, who after many vicissitudes had attracted public attention by gaining a medal for an invention in textile machinery at the industrial exhibition in Paris, was called by Napoleon and his minister, Carnot, to a position in the Conservatoire des Arts et Métiers, where he found the Vaucanson machine whose mechanism suggested the improvements which

finally were developed by Jacquard to their present form (p. 153). The opposition to the introduction of the Jacquard machine was so violent that the inventor was several times attacked by a mob and barely escaped with his life. The Conseil des Prudhommes, who were appointed to watch over the interests of the Lyonnese trade, so completely entered into the feeling which prompted this opposition that they broke up his model in the public square. The invention, however, was not lost; the machine was constructed elsewhere, and gradually made its way into England and France. After some years had passed it proved of great practical value, and in 1840, on the spot where the model was destroyed, a statue of Jacquard was erected.

1. Machines for Preparing Cotton for Spinning.

It is a characteristic feature of spinning by machinery that the process does not, as in spinning by hand, proceed in one operation from the simple fibres to the perfected thread, but that it first produces a strong ribbon-like semi-fabric, technically known as a "sliver," in which the fibres, freed from foreign substances, are arranged together in regular straight and parallel order. This semi-fabric is then gradually drawn out to the desired degree of fineness, and the requisite firmness is finally imparted to it by twisting. Hence, in considering the subject of spinning by machinery, the entire process may be divided into two operations: (1) the preparation of the sliver (ginning, opening, and carding) and (2) the conversion of the sliver by drawing and spinning into threads. The principal machines used for the first process are represented on Plates 35 and 36, and those employed for the second process are shown on Plates 37 and 38.

Ginning: Whitney Saw-gin.—The primary operation in spinning cotton by machinery is "ginning"—that is, the separating of the fibre from the seed. Figures 1 and 2 (*pl.* 35) show in vertical section two machines, termed "cotton-gins," which are used for this purpose. The principal feature of the so-called "saw-gin" (*fig.* 2) invented by Eli Whitney is a cylinder (*a*) armed with circular saws, a roller-brush (*b*), and a grate (*c, c*) composed of iron rods. This grate serves for the removal of the seeds, and is fastened below to the plate *d*, and, together with the plate, can be set in a suitable position in relation to the teeth of the saw-blades by means of the screw *e*, which enters into the cross-piece *f*. To permit the varying arrangements of the grate the rods of the latter are also connected above with a plate, which is secured by hinge-joints (*g*) to the upper cross-piece *h*. The hopper for the reception of the cotton is made up on the two sides by the walls of the frame, in front by the adjustable plate *i*, below by the grate, and in rear by the curved plate *l*. The plate *i* can be set backward and forward or higher and lower and screwed to the side walls by the screw-bolt *n*. The object of this is to set the comb *k*, placed below at *i*, in such a position regarding the cylinder which carries the saw-blades that the seed can pass with the requisite velocity through the opening between *k* and *c*. The curved plate *l* can be turned at *o* and

secured by a screw (m) in a more or less inclined position, whereby the material to be worked is correspondingly pressed against the saw-blades.

If a more forcible action is requisite to gin the cotton properly, the plate d is depressed, whereby the teeth are projected farther over the grate, the curved plate l being at the same time moved forward. By giving the plate d the opposite position the fibres are less forcibly acted upon and the work proceeds more slowly. In case the seed does not fall freely enough from the machine, the plate i must be placed higher and farther forward; if the seed runs out too rapidly and is not sufficiently cleaned, the plate is to be set in the opposite position. At the rear of the cylinder, between the saw-blades, is placed a second or cleansing grate in a vertical position. It is secured to the plate p, which beneath the cross-piece h can be pushed up or down in grooves in the side frames of the machine. It consists of separate rods (q), which are connected with p only by a screw (r), and if desired may receive a slightly lateral motion between the saw-blades. Between the lower end of the rods q and a screen covered with tin plate (s) is a slit, through which the coarsest particles of dirt pass out in the direction of the arrow 1, the finer particles passing round and falling on the other side, as indicated by the arrow 2, while the cotton fibres themselves ascend in the direction of the arrow 3 on the plane t, also covered with tin plate, underneath which the space for the accumulation of the impurities is shut off by the screen u.

Comb-gin.—Though the saw-gin is very effective, it somewhat injures the quality of the cotton by tearing the fibres; to prevent this the comb-gin has been introduced (perspective, *pl.* 35, *fig.* 3; vertical section, *fig.* 1). In Figure 1, A represents a cylinder covered with rough leather which rotates in the direction of the arrow and carries with it the fibres of raw cotton fed to it. The blades a placed close to the periphery of the cylinder retain the seeds, which, liberated from the bundles of fibres by two blades ($b\ b'$) oscillating rapidly up and down, fall between the rods of the grate (i). The blades $b\ b'$ are fastened to the ends of the levers c, and from a shaft placed in the lower portion of the frame (B) receive their motion by means of two eccentrics and two eccentric-rods ($D\ d$). The raw cotton is spread out upon an endless rotating apron running over two rolls and receiving from them a forward motion, which carries the cotton under the grooved roll h, after which it is thrown into the trough $H\ I$ by a toothed roll (s), and is finally pushed against the leather-covered roll A by means of the oscillating comb J. The rail a is secured to the frame $F\ j$ by the screw e. The cylinder A is revolved from the driving-shaft by means of a belt and a pulley (L'). The ginned cotton is finally removed from the cylinder A by a rapidly revolving fluted roll (G).

Willow.—The cotton is always ginned on the plantations where it is produced, and for transportation is packed in bales with the assistance of powerful presses: it therefore requires subsequent loosening at the factories by special machines, one of which, the so-called "willow," is shown in Figure 4. This consists of a wooden casing in which rapidly revolve

two horizontal shafts provided with beating arms. These arms are so placed that those on the one shaft pass between those on the other, and, besides, a number of stationary rods arranged in two rows in the interior of the casing correspond to the interspaces between the shafts. By introducing the cotton taken from the bales into the interior of the casing by means of an endless feeding-apron and two feeding-rolls, the firmly compressed masses are loosened and reduced to small bunches.

Opener.—A still more effective machine, the "opener" (*pl.* 35, *fig.* 5), performs the work by means of four drums provided with thumb-like elevations, which receive the cotton also from a feeding-apparatus and throw it repeatedly against rows of similar but stationary teeth. Below the drums is arranged a grate, composed of thin iron rods, through which fall all foreign bodies (sand, seed, pieces of leaves, etc.). The cotton thus loosened and freed from the coarser contaminations passes through two sieve-drums with fine meshes, from the interior of which air is constantly drawn by an exhaust-fan. The cotton, thus drawn against the periphery of these sieve-drums, is freed from dust and very short fibres by the powerful current of air. The prepared cotton is removed by an endless apron.

Batting-and-lapping Machine.—The most important preparatory machine, and one closely allied in its action to those described above, is the batting-machine (scutcher, beater, or opener), which is generally combined with an apparatus for the formation of the laps, and is known as the "lapper" (section, *fig.* 6). The cotton is spread upon an endless feeding-apron and conveyed by two pairs of fluted rolls to a beater in the interior of the casing *a*. This beater consists of two or three steel rails connected by several cross-arms with a shaft revolving at high speed. The rails beat in rapid succession and with great velocity upon the cotton coming from the feeding-rolls, thus further reducing any bunches still present. Below the beater is a grate, for the escape of coarser detritus. The loosened cotton next passes to the so-called "flying-space" *b*, and consolidates to a flor on the periphery of the sieve-drum *c*, from which the air is constantly drawn. The flor is detached by the pair of rolls *d*, and, being further compacted between the rolls *e*, *f*, *g*, *h*, is finally rolled together upon a large wooden bobbin to a lap. To facilitate the detachment of the flor from the sieve-drum (*c*) the current of air is cut off at the appropriate place by a shield firmly connected with the shaft of the sieve by means of the lever *m* loaded with the weight *n*.

Figure 8 shows a modified form of the batting-and-lapping machine: *a* designates the beater; *c*, *d*, the grate; *b*, the flying-space; *e* and *f*, two endless sieve-cloths, replacing the sieve-drum; and *g*, the compressing-rollers, back of which is the attachment producing the laps and known as the "lapper." At *h* and *i* enter the suction-channels *l* and *m*, which lead to a fan, and by means of which the dust is removed from the cotton. *k* is a receptacle for the coarser contaminations, and serves at the same time for shutting off the air from below. To be enabled, when working short cotton, to bring the effective edge of the beater as close as possible

to the place where the fleece is held, the feeding-rolls are frequently replaced, as in Figure 7 (*pl.* 35), by a tray (*a*) and a roll (*b*) set with sharp points, which can be brought close to the beater carried by the arms *g*. This arrangement is called "tray-feeding." The external appearance of an opener and lapper is shown in perspective views in Figure 9 (*pl.* 35) and Figure 1 (*pl.* 36).

Carding.—From the previously explained machines the cotton is delivered in the form of a very clean downy fleece, known as a "lap," having its constituent fibres thoroughly disentangled, yet not parallel. As the parallel condition is necessary before forming the roving from which the yarn is to be wrought, the lap must be subjected to the process known as "carding." As a regular and perfect roving is one of the first requisites for producing a perfect cloth, the carding is an important operation, as is evidenced by the constant efforts made by builders to produce carding-machines of increased capacity and higher quality of result. The carder of to-day has many advantages not possessed by his predecessors of the last generation, his card-clothing and auxiliary machines being so much advanced and so superior that he cannot fail to obtain better results from the same quality of cotton. The object of the carding-engine is further to separate the bunches of fibres composing the lap by means of the very fine wires of the card-clothing, and then to re-form the fibres into a roll (the roving) in which the fibres are uniformly parallel.

Carding is one of the most important processes required in manufacturing raw cotton-fibre into thread. That the work may be well done two conditions are requisite: first, in order to allow a "true" setting and to prevent unequal pressure of the working parts on the bearings and framework, the carding-engine should be placed on a solid level floor where there will be no vibration: the ground-floor of the mill-building furnishes the most suitable location; and secondly, for the different parts of the carding-engine there should be selected proper card-clothing, upon which good carding mainly depends. The principle of the card-clothing will be understood from the following explanation.

Card-clothing consists of strips of leather in which are inserted fine wires, called "needles" or "teeth" (dents), having their projecting ends slightly bent in one direction. The teeth, which vary in size according to the quality of cotton to be worked, must be equally distributed and equally inclined over the surface of the leather. The card-clothing is fastened to flat or cylindrical surfaces of wood or metal, and the cotton is passed between two or more such clothed surfaces. It will be readily seen that the card-clothing is a very important factor in carding cotton, as it performs the peculiar function of separating the fibres and again combining them.

Figure 6 (*pl.* 36) shows a section of card-clothing for a "licker-in" roller. As this is the card-clothing with which the cotton first comes in contact, it must be strong, so as to remain uninjured by any impurities adhering to the cotton. Figure 7 illustrates the card-clothing used for

covering the main cylinder of a carding-engine when working a good staple cotton; Figure 8 (*pl. 36*) is the card-clothing required for the "dirt-roller." The latter clothing is not so close set as the former, the purpose being to receive in its interstices the seed, leaves, and other impurities in the cotton, taken from the surface of the close-set card-clothing which covers the main cylinder. Card-clothing is designated by numerals, which indicate the number of wires to the square inch. The wires are either flattened or round, coarse or fine, according to their required purpose.

Figures 4 and 5 represent two pairs of card-clothing bands of different modes of action. In Figure 4 the needles are set opposite one another in the direction of their points. Supposing the lower card-clothing covered (in any manner) with cotton and the upper (*b*) moved over it to the right, hence in the direction opposite that of the arrow, the dents or teeth of the upper card-clothing will remove a portion of the cotton from all places of the lower where it is in excess and deposit it on those places which are empty or not sufficiently filled, the result of this simple operation being the separation of the fibres and their uniform distribution between the two surfaces. Figure 5 shows two strips of card-clothing with dents bent in the same direction. If the upper card (*a*) be filled with cotton and drawn over the lower in the direction of the arrow, the entire material will be transferred to the lower.

Carding-machine.—Upon the latter two modes of application is based the action of the carding-machine, also termed "carding-engine." Around a large cylinder or drum covered with card-clothing and revolving at great speed are placed a number of small rollers, called "workers" and "strippers," or a number of stationary top-cards, or both combined, so arranged that the cotton introduced by a feeding-apparatus is separated into filaments and wrought into a flat, narrow strip or ribbon, termed a "sliver." This latter is then further drawn out, and thus reduced to a yet thinner and more attenuated state. The carding-engine shown in Figure 3 contains workers and clearers as well as top-cards and an automatic cleaning-apparatus for the latter, thus representing this kind of machine in its most advanced form. Figure 2 shows a revolving flat carding-engine.

2. PREPARATORY MACHINES AND SPINNING-MACHINES.

Drawing.—The cotton, having been wrought by the carding-engine or other preparatory machine so as to form a continuous sliver or ribbon of some consistency, must next be converted into drawings. To obtain the utmost uniformity as regards thickness, several ribbons or slivers are combined by "doubling" and the fibres straightened out by stretching these ribbons. It is then made gradually thinner by continued stretching or "drawing," being at the same time slightly twisted, which gives it the requisite consistency of "roving." This, which may be considered as a preparatory yarn, is finally reduced to the fineness and firmness required by more forcible twisting or fine spinning.

Canal Drawing-machine.—The mere placing together of several ribbons or slivers as they come from a train of carding-machines is effected by the canal drawing-machine (*pl.* 37, *fig.* 1). This machine contains two wooden bobbins, to be used alternately, upon which the narrow ribbons to be widened out are wound in regular layers. This is effected by alternately resting the bobbins with a suitable pressure upon two fluted rollers, which revolve uniformly around their axes and rotate the bobbin with a constant velocity.

Doubling-machine.—The regular combination of the ribbons to be doubled takes place upon an endless cloth running horizontally in a long box open on the top, the so-called "canal," at the end of a train of carding-engines. It being improbable that in placing the ribbons together a somewhat thicker place in one will meet a similar thick place in all the others, but rather that the defective places of the separate slivers will vary in position in the finished ribbon, it is evident that the uniformity of the product as regards thickness is increased by this doubling process. The above-described doubling-machine is chiefly used in cotton-mills between the first and the second carding process, though sometimes after the completion of the latter.

Combined Drawing- and Doubling-machine.—A machine belonging to this group is the drawing-machine (*fig.* 3), which, serving for the simultaneous doubling and stretching (drawing), finds quite general application in spinning the various textile fibres. The effective parts of the machine are rollers arranged in pairs, which catch the doubled ribbon and through their different velocities draw it out to five or six times its original length, thus stretching and straightening the fibres. The ribbons thus manipulated are caught in sheet-iron cans, two of which are shown in the Figure. In spinning establishments producing yarns of high counts these machines are called "spreading-" or "drawing-frames," and, being generally used several times in succession to obtain the fibres in the completely stretched and uniform condition of the ribbon, the terms "first," "second," "third," etc., drawing, spreading, or slubbing are used.

Roving.—As long as the doubling and drawing proceed together the sliver retains sufficient tenacity to sustain without injury the operations of placing it in the can and of taking it out. If, however, doubling is to be entirely omitted or is to be unequal to the drawing, the ribbon gradually becomes so tender that it may tear if means are not provided to increase its strength. The requisite strength is imparted by a temporary or permanent twisting of the ribbons, by which the fibres, being brought closer together, are more intimately intertwined and adhere more firmly. This bringing together of the fibres must, however, not be carried too far, as thereby a further drawing would be rendered difficult or impossible. The machines by means of which the drawing is effected simultaneously with a twisting to increase the consistency of the thread are called "roving-machines," of which there are two kinds, one for a temporary ("false") twist and the other for a permanent twist.

Temporary-twist Roving-machine.—Figure 2 (*pl.* 37) exhibits a temporary-twist roving-machine. Besides the ordinary drawing-frame, there is an apparatus which, after the ribbons or threads have been stretched, twists them alternately to the left and right, the action being similar to that of rolling a filament between the palms of the hands. This twisting-apparatus consists, for each sliver, of an endless strip of leather stretched over two rollers, a leather-covered cylinder being pressed upon the strips in the centre of the upper one. These two mechanisms, having a continuous revolving motion, catch the ribbon between them and convey it from the drawing-frame to the tin can, while an alternate pushing backward and forward in a longitudinal direction normal to that of the sliver effects the twisting of the sliver in alternate directions.

Permanent-twist Roving-machines.—The fly-frames shown in Figures 4 and 5 will serve as representatives of roving-frames for permanent twist. Here the stretched ribbon is carried by the front cylinders to the central aperture of a fork-like fly revolving at great speed. It then passes through a hollow arm of the fly to a wooden bobbin placed inside, upon the axis or spindle of the fly. This bobbin revolves independently at a sufficient rate of speed to wrap up in regular windings the length of thread furnished by the drawing-frame. Thus it will be seen that between the drawing-frame and the fly a permanent twist and the requisite degree of solidity are imparted to the thread, the regular winding to a bobbin being effected at the same time. Each flying-frame contains a large number of spindles (from forty to one hundred) with flies and bobbins arranged in two rows, so that an equal number of rovings can be simultaneously made.

Spinning-machines.—The last step in the production of yarns is fine spinning, the rovings being sufficiently drawn out to attain the fineness required for the yarn. The thread now receives a permanent and sufficiently sharp twist, which brings the fibres closely together and gives them a helical position; and finally the thread, whose length has now become considerable, must be wound up in a regular manner, so as subsequently to allow of a ready unwinding. According as to whether these three operations are carried on simultaneously or alternately, two kinds of fine-spinning machines are distinguished in the manufacture of cotton yarns—namely, the water-frame and the mule-jenny.

Water-frame.—The arrangement of the water-frame very much resembles that of the fly-frame (*figs.* 4, 5), containing, like it, a drawing-frame, a fly effecting the twist for each thread, and a wooden bobbin (*figs.* 6, 7) for the reception of the yarn. While in the fly-frame, however, the bobbins are made to revolve by distinct mechanical movements adapted to the tender condition of the rovings, in the water-frame the bobbin is made to revolve by the pull of the yarn, which is kept sufficiently stretched by the weight of the bobbin and its friction upon the copping-rail. It will be seen from this arrangement that the yarn, to prevent its frequent breaking, must possess a certain degree of firmness, and this is imparted to it by sharper twisting.

Mule-jenny.—Hence, for soft yarns, such as are used in the production of many woven articles, and which require a slighter twist, the water-frame is not available and is replaced by the mule-jenny, shown in various arrangements in Figure 9 (*pl.* 37) and Figures 1 and 2 (*pl.* 38). Though the stretching and twisting of the thread are simultaneously effected by this machine, the winding up is done intermittently each time after the completion of a certain length of thread (about 6 feet), the actual spinning being interrupted in the mean while. The yarn is not wound on wooden bobbins such as are shown in Figures 6 and 7 (*pl.* 37), but on slender conical iron or steel spindles whose shape is represented in Figure 8.

There is a remarkable difference between the mule used for the production of smooth yarn from cotton, long sheep's wool (worsted), etc., and that for rough carded yarns from short wool. In the first, where there is already a roving of great uniformity, the stretching is effected by means of an ordinary drawing-frame, but in the latter between a pair of feeding-rollers and the spindle which serves for twisting as well as for winding, and which continues to recede from the feeding-rollers after the latter have come to a stand-still. The spindles, on whose periphery the thread is fastened, stand slightly inclined toward the vertical and revolve at great speed during the entire spinning process, thus imparting a permanent twist to the thread. If, now, the twisting and drawing be effected at the same time, as by the mule for carded wool, the twists affect the threads first upon the thin places, which oppose the least resistance to the twisting, whereby they obtain such a solidity that in the drawing they oppose a greater resistance than the remaining thicker but less twisted places, the drawing thus chiefly affecting the latter. The equalizing required on account of the uneven thickness of the rovings is in the process of fine spinning thus attained at the same time. This also explains the somewhat different arrangement of the mechanism of the mule for carded wool.

Self-acting Mules.—A large number of threads (from two hundred to one thousand) are produced by a mule at the same time. A number of spindles corresponding to the number of threads to be spun stand in a row on a carriage, which runs on iron rails, alternately receding from and approaching the drawing-frame during the spinning and winding periods respectively. With the so-called "hand-mules" the motion of the carriage as well as the rotation of the spindles and the distribution of the windings on the spindle by a workman takes place during the latter period, while with the self-acting mules, which are chiefly used, all motions, without exception, are derived from the driving-shaft. Figure 9 (*pl.* 37) and Figures 3 and 5 (*pl.* 38) show the external appearance of different self-acting mules.

3. MACHINES FOR PREPARING WOOL, ETC. FOR SPINNING.

Wool-burring Machine.—If we now turn our attention to the machines for the preparation of wool fibre, we have first to consider the apparatus

for cleaning the wool. Figures 2 and 3 (*pl.* 39) represent what are known as burring-machines, which serve to free the wool without loss from the burrs that frequently adhere to it. The effective part of such machines is a cylinder provided with fine steel combs set tangentially, upon whose periphery the wool is so brushed that the burrs lie free upon the outside and are knocked off by a quickly revolving knife-roller.

Wool-washing Machine.—After the locks of wool have been opened and cleaned of impurities in the burring-machine, the wool is transferred to the washing-apparatus, which serves for the removal of the oily substances adhering to the wool. To dissolve the adhering fat or "suint" the wool is treated with warm soapy water.

The wool-washing machine (*fig.* 4) consists of a series of stationary rakes or racks, alternating with movable ones, which are actuated by a crank-motion and arranged in a long box partly filled with scouring-liquor. Such machines are built with one, two, or three bowls. The liquor in the first bowl soon becomes dirty and must be drawn off. When this is done, the liquor from the second bowl is drawn, by means of an injector attached to the side of the machine, into the first bowl, and a new liquor is prepared for the second bowl. In a three-bowl machine this process is used between the second and third bowls. In some instances the wool is first scoured, and, if making wool-dyed fabrics, colored, before it is burr-picked. In most instances the wool is colored before being carded and spun. If colored after scouring, it is submitted to the action of the hydro-extractor (*pl.* 38, *figs.* 6, 7). Figure 6 represents one of these machines operated by belt and friction cones, and Figure 7 a similar one operated by a direct-acting steam-engine. After the wool is colored and repeatedly washed, or only scoured—in which condition it would be used either for piece-dyed goods or white flannels, etc.—it is submitted to the wool-drying machine.

Wool-picker.—After being thoroughly dried the wool is subjected to the common picker or opening-machine (*pl.* 39, *fig.* 1), by which it is loosened or opened. In a semi-cylindrical casing there revolves a large cylinder having strong iron spikes, to which the wool is supplied by means of a feeding-apparatus consisting of an endless apron of wooden slats and fluted rollers, the loosened wool being thrown out through an aperture opposite the feeding-apparatus. When used for working wool moistened with oil for the carding process, this machine is technically known as the "wool-picker."

Wool-carding Machine.—Entirely unlike the method of cotton-roving is the process of producing rovings from the sliver of the last carding in spinning wool, the latter being effected by an apparatus attached to the carding-engine itself. While in spinning cotton, flax, and worsted yarn the object is to produce smooth, even rovings with the separate fibres drawn straight, in spinning wool the object is to obtain a rough thread of fibres lying cross-wise and with their upper ends projecting from the surface, so that the tissue (cloth) spun from such threads will be capable of being "fulled"—that is, so that the threads lying alongside one another

may readily "felt" under the influence of moisture, heat, and kneading. For this reason the doubling and drawing processes are dispensed with, and the object is attained in one operation by pulling the sliver coming from the carding-engine cross-wise into roving-threads, which are then converted into roundish threads by the apparatus referred to above. This pulling apart of the fibres is effected on the periphery of the "doffing"-cylinders, following immediately behind the carding-cylinder. The cylinders are covered with narrow strips of card-clothing separated from one another by short intervals, being thus arranged to receive the wool from alternate zones on the main cylinder.

To prevent these strips from coming in contact with one another their detachment is effected by two combs, the first of which is provided with teeth for the first, third, fifth strip, etc., and the other for the second, fourth, sixth strip, etc., two rubbing and two winding attachments being also used. Such a carding-engine is shown in Figure 1 (*pl.* 40), while a carding-engine with only one comb is represented in Figure 2. Both machines are of German construction. Figure 5 (*pl.* 39) represents the "finisher" of an American carding-machine.

The complete carding-machine consists of three individual machines, known as the "first breaker," the "second breaker," and the "finisher" (*pl.* 41, *figs.* 2–4), which constitute what is termed "one set." Figures 2 and 5 illustrate the first breaker, which is that part of the "set" with which the wool first comes in contact. In Figure 5, at the left of the machine, extends the feed-apron, upon which the wool is spread; this apron is similar to the one used on the wool-picker and brings the wool in contact with the first pair of rollers, which are known as the "dirt-rollers." This spreading of the wool upon the apron is also now done automatically by means of the Bramwell feed (*fig.* 2). Figure 3 illustrates what is known as the "second breaker," through which the drawing passes before reaching the finisher (*fig.* 4). Figure 1 illustrates a similar finisher with the Apperly feed attached. This feed is used to make automatic connection between the second breaker and the finisher. Figure 6 shows a Garnett machine and card combined. This machine is for opening, for reworking, the "hard waste"—that is, the yarn waste—from the weave-room.

Quite different from wool-carding is wool-combing, known as "worsted-combing." In the latter process the object is to produce as smooth a thread as possible, since fabrics made of this yarn require very little if any felting or falling. From the worsted-card (*pl.* 40, *fig.* 3) the drawing goes to the comb, and thence to the spinning-frame.

Figures 1, 2, and 4 (*pl.* 38) illustrate a mule for spinning woollen yarn from the roving as it leaves the finisher-card, where, by means of rubbing, it has received sufficient solidity to be put on roving-spools, which are so inserted in a frame in the mule as to allow rewinding of the roving for drawing it to the required size, as well as for imparting the necessary twist.

Flax is a term employed to denote both the fibre of the flax-plant and the plant itself. There is abundant evidence that this important plant has been cultivated from remote antiquity (see Gen. xli. 42) for the strong fibres of the bark, which are manufactured into linen. To prepare it for spinning and weaving the following preliminary processes are requisite.

The Rippling Process, which has for its object the removal of the seed-capsules, is the first to which the flax-plant is subjected after being pulled up by the root. It consists in drawing by hand successive bundles of flax straw through the upright prongs of large fixed iron combs, or "ripples." If the plant, after having been pulled, has been dried, the removal of the seeds is effected by means of the "seeding-machine," which consists of a pair of iron rollers, between which the flax is passed.

Retting is an important operation which is performed for the purpose of separating the fibre from the woody "shive" or core, and also for decomposing and removing certain adherent glutinous substances. Two processes—namely, cold-water retting and dew-retting—have been practised from the earliest times. Warm-water retting was adopted in England in 1846.

Cold-water Retting, which is the usual process, requires a pond of pure soft water not more than 4 feet in depth, and for retting an acre of flax it is calculated that it should be 50 feet long and 9 feet broad. In the pond are placed the rippled stalks, which, tied in bundles and covered with straw or sods, have placed above them stones of sufficient weight to keep the flax submerged. Under favorable circumstances a fermentation is immediately induced through the influence of heat and moisture. The process is generally completed in about two weeks, when the flax is spread out and allowed to remain for several days in the open air; it is then ready for breaking and scutching.

Dew-retting, which dispenses with fermentation, is accomplished by subjecting the spread-out flax to the influence of air, sunlight, dews, and rain.

Warm-water Retting employs tanks, in which water is raised to a temperature of from 75° to 95° Fahr. during the time the flax is kept in the tanks, which is from fifty to sixty hours. The different colors in flax are due to the different systems of retting.

Flax-breaking Machines.—Of the auxiliary machines for the treatment of flax the two brakes shown in Figures 7 and 8 (*pl.* 41) are especially characteristic. After the destruction by the retting process of the gummy matter uniting the fibres with the stem these brakes serve to crack, at short intervals, the woody portions of the flax-stem, so that their complete removal can be readily accomplished by the beating- or scutching-machine. In Figure 7 the breaker consists of two rows or groups of cast-iron levers, which move toward each other with an oscillating motion, so that their edges slightly pass over one another and the flax-stems held between them are broken. Figure 8 represents Guild's breaking-machine, whose effective

portion consists of two pairs of fluted rollers, between which the flax-stems, spread out upon a table, have to pass.

Scutching.—A scutch is an implement employed for dressing flax or hemp. By its use the fibre is entirely freed from the woody core. Scutching is done by hand or by scutching-mills driven by water or by steam-power. A variety of machines and processes has been introduced for the purpose of economizing labor and of improving the fibre of the flax, both with reference to cleanliness and to the production of the least amount of scutching-tow.

Flax-hackling.—The flax fibres, thus freed from the woody portions, are subsequently subjected to the so-called "hackling" process, by which the long fibres ("line") are separated from the short fibres ("tow"). By piecing together separate lengths the long flax is converted in a very simple manner into an endless tape or ribbon, while for working the tow there is used the carding-engine, which is the universal machine for converting all short-fibred material (requiring spinning) into a uniform roving, which can then be readily twisted into a thread.

Silk.—In producing the silk-thread neither roving nor carding machines are necessary, since the thread is spun by the silkworm around itself when it enters the pupa or chrysalis state, and for textile purposes needs only to be unwound from the cocoon.

Reeling.—The cocoons, after the chrysalides they contain have been killed either by dry heat, exposure to steam, or in water heated to about 200° Fahr., are sorted and submitted to the reeling process, in preparation for which a number are thrown into a basin of warm water, in order to soften the gummy envelope of the fibres and to permit their ready separation from the cocoon. During the reeling process two threads, composed of an equal number of fibres, are passed separately through two perforated agate guides. After being crossed at a given point they are again separated and passed through a second pair of guides, and next through the distributing guides to the reel, from which they are taken off in hanks ready for market.

Silk-throwing.—Before using reeled silk for textile purposes two or more of the threads are "thrown" together and slightly twisted. In this manner are produced the various kinds of silks known as "organzine," "tram," "embroidery," "sewing," etc.

The next process is what is known as "shaking out," whose object is to beat out or open out the hanks that they may present a uniform appearance. Following is the "stringing" process, which is performed either by hand or by machine, and whose object is to complete the separation of the double silk fibre into its constituent fibres and to impart to them an additional lustre. Some silks which require a special lustre are subsequently subjected to a special process, known as "silk lustring." This is effected by submitting the hanks to a gentle stretching between two polished steel rollers enclosed in a cast-iron box. During the rotation of the cylinders steam is admitted at a moderate temperature.

4. PREPARATORY MACHINES FOR WEAVING, AND LOOMS.

The various machines represented on Plates 42 to 47 serve for the production of woven textile fabrics—that is to say, of fabrics composed of two distinct systems of threads which interlace at right angles. The threads which run lengthwise in the fabric are technically known as the "warp;" those which run crosswise are termed the "filling." The raw materials usually employed in the production of woven fabrics are cotton, wool, silk, flax, jute, etc.

The Warp: Chain Warping.—The warp consists of numerous individual threads, which before the actual weaving operation must be placed parallel and near one another by a special manipulation known as "warping" or "dressing;" and by an operation termed "beaming" these threads are wound tightly upon a wooden roller, called the "warp-beam." There are two methods of warping—namely, chain warping and section warping. Chain warping (*pl.* 42, *fig.* 1) derives its name from the manner in which the warp is taken from the reel. After the warp has been made it is drawn from the reel by hand and looped up in a succession of links like a chain. It then goes to the dyehouse, to be dyed or sized, as may be required. Reels—or, as they are generally called, "warping-mills"—vary in height and circumference according to the grade and quantity of work. After the warp has been linked in a chain it is put on the beaming-machine. Figure 2 is an illustration of a good form of beaming-machine, showing the rolls, etc. For warping cotton a different machine is frequently used (*fig.* 3), the thread being passed directly from the bobbins and wound upon a beam. This machine is generally provided with an attachment which, should any thread break or the bobbin run out of yarn, immediately stops the machine until the thread is tied or replaced.

Section Warping, mainly practised in the manufacture of woollen and worsted fabrics, is clearly illustrated in Figures 1, 4, and 5 (*pl.* 43). Figure 1 represents the sizing-machine, and Figure 4 the section reel used in connection with the former. Section reels are made about 4 yards in circumference and from 40 to 120 inches long, according to the work to be done. Most reels have twelve long rails, called "pin-rails," provided with numerous small holes from $\frac{3}{16}$ to $\frac{1}{4}$ of an inch in diameter, systematically arranged, into which the operative puts pins from 3 to 4 inches in length, to act as "builders" and to limit the width of the section. For woollen and worsted fabrics the warp-yarn is generally wound on long spools, each containing from twenty-five to fifty ends. Figure 5 shows a machine for winding these long spools.

The Filling consists of single threads running in straight layers to and fro across the entire width of the tissue, returning at the edges and imparting to the web the requisite firmness. The combination of the warp with the filling for the formation of a web can be effected in an endless variety of ways, technically known as the different "weaves." These

are generally divided into three distinct classes, termed "foundation weaves"—namely, the plain, the twills, and the satins—which form the basis of further subdivisions, classified as "derivative weaves."

Cotton Weave.—Figure 3 (*pl.* 43) represents a fabric produced by what is technically known as the plain or "cotton weave." In this diagram two distinct sets of threads crossing each other at right angles and interlacing alternately are visible. The threads (W) which run lengthwise in the fabric are the warp-threads; the transverse threads (F) are the filling. Figure 6 shows the design or pattern, executed to correspond with the fabric sample, Figure 2, the shaded squares indicating warp up and the empty squares representing filling up. Figure 6 is a section of a fabric woven on "plain" weave, showing one warp-thread light (1), the other shaded (2). The filling is represented in full black. Figure 2 shows that this weave produces a very firm interlacing of the two systems of threads employed; in fact, it is the most frequent interchange of warp and filling possible. This weave produces a strong fabric, as, by reason of the interlacing, each thread supports the other to the fullest extent.

Harness.—The portion of the loom which effects the regular separation of the warp-threads (technically known as the "opening of the shed") is called the harness, its arrangement for weaving "plain" being shown in Figure 8, in which a, b is the horizontally stretched warp, c the so-called "reed," a light wooden frame as long as the width of the fabric and provided with a large number of parallel vertical strips of metal (dents, *fig.* 11), between which are passed the warp-threads, either separately or by twos, threes, etc. By this means the warp-threads are kept uniformly distributed over the width of the loom, and the pushing together of the introduced filling ("beating up of the filling") is readily effected by pushing the reed toward the breast-beam of the loom.

Harness-frame and Heddles.—Figure 9 shows the so-called "harness-frame" and "heddles," consisting of two horizontal laths with a number of twines with small wire loops ("mails"), through which the warp-threads are drawn. Figure 12 is another shape of a harness or harness-shaft more frequently in use than the one previously shown. It consists of a frame A and the iron rod B for holding the heddles C. Through the eyes (D) of the heddles the warp-threads are drawn, as illustrated by E. For drawing a warp into its set of harness two persons are required. The "drawer in" inserts his "drawing-in hook" through the eye of the heddle toward the second person, called the "hander in." The latter inserts one of the warp-threads in the eye of the hook, which in turn is pulled out of the heddle-eye by the first drawer in.

The Shuttle for the introduction of the filling is shown in Figures 13 to 15. It is a boat-shaped piece of wood with metal-pointed ends, and is hollowed out for the reception of the bobbin, which is wound with the filling and placed upon a spindle in the shuttle. From this bobbin the filling is unwound either in a direction normal to the axis or parallel to it. In the first case (*fig.* 14), the bobbin g revolving around the spindle, cylindrical

convolutions are formed; but in the second (*pl.* 43, *fig.* 15), the bobbin *s* being fixed upon the spindle, conical layers are produced. The filling passes out through a hole in the side of the shuttle, which, passing through the shed, is drawn across the width formed by the warp. Figure 13 is a shuttle used in weaving cloth in power-looms. Figure 7 shows the lay or batten and reed as used in hand-looms; *H* represents the shuttle-race supported by the arms *E* attached to the cross-bar *B*, which is suspended by means of two steel prisms or points, so that it can be turned to the frame of the loom, and which is given pendulum-like oscillations by the left hand of the weaver. The reed sits between the shuttle-race *H* and its cover *P*.

Temples.—To prevent a too forcible and irregular contraction of the warp by the tension of the filling, which in the beating up is forced to assume an undulatory shape, the weaver uses special appliances, called "temples" (*fig.* 10), consisting of two pieces of hard wood connected by threads and provided at the ends with pins. The two pieces of wood form an obtuse angle, and by inserting these pins near the edge of the fabric and adjusting the whole upon the cloth in the manner of a joint-lever there is produced in the direction of the width of the cloth a suitable tension, which resists the pull of the filling. The temples are shifted as the formation of the cloth progresses. In the same manner, that the play of the batten may be constantly continued in one place, the cloth itself must move in the direction of the arrow (*fig.* 8). For this purpose it is adjusted to wrap upon a roller (the cloth-beam), which from time to time is turned by the weaver or at short intervals by a mechanism driven by the batten.

Looms.—The art of weaving antedates all authentic records. References to woven goods occur at an early period of Scripture history and they are numerous in the Mosaic period. Pliny accords to the Egyptians the invention of the loom, in which, as shown by the temple-paintings, the web was either horizontal or perpendicular. The finest of the Egyptian mummy-cloths have about sixty-four threads to the inch in the warp, and about one hundred and forty threads in the filling. In the looms of the Greeks and Romans the warp also ran either horizontally or vertically. Their shuttles, made of box-wood, were pointed at each end, and in a cavity made in each shuttle there was placed either a quill (*pira*) or a bobbin, on which the filling was wound, and which revolved as the yarn unwound and passed through a hole in the side of the shuttle.

Hand-loom.—Figure 8 (*pl.* 34) exhibits a simple form of horizontal hand-loom employed in Europe during the Middle Ages, and Figure 7 is a representation of a loom now in use among the peasants of India. With the latter loom the richest gold-and-silk fabrics and the most elaborate patterns are woven, frequently by travelling weavers who carry with them their apparatus, whose parts they can quickly adjust. Figure 12 (*pl.* 44) illustrates a hand-loom, *A*, *A*, *A*, *A* being the frame, *t* the treadles for operating the harness *b*, *d*, actuating around rollers *a*, *l* the lay, and *k* the breast-

beam, around which the woven cloth passes to the cloth-beam. In the rear of the loom is the warp-beam, around which the warp-threads are wrapped before passing into the harness.

In plain cloth, the threads which run lengthwise constitute the "warp," while those which run crosswise are variously termed the "weft" or the "filling." The warp is divided into two parts, one of which is raised while the other is lowered to allow the filling to pass between them, the space thus formed being termed the "shed." The principal working parts of the hand- and power-loom are practically the same, as will be apparent from the succeeding description.

For plain weaving two harness-shafts are united by two cords passing over pulleys (*e; pl.* 43, *fig.* 8), and below by two other cords with the treadles F^1, F^2, which are pivoted on the axis g, and which the weaver alternately depresses with the feet. Suppose, now, the odd-numbered warp-threads (first, third, fifth, etc.) to be drawn through the heddle-eyes of the heddle d^1 and the even-numbered through those of d^2; it is evident that by depressing the treadle F^2 the heddle d^2 will be drawn down from its central position and d^1 will be drawn up, and that as such separation of the warp-threads (formation of a shed) takes place all the odd-numbered warp-threads will be carried above and all the even-numbered ones below the original central position. In the angular shed formed by the heddles d^1, d^2 between the already finished cloth a and the reed c, the filling is introduced by means of the shuttle, which is hollowed out, to contain the "cop" or bobbin. By a vigorous movement (beating up) of the reed the filling is driven close to the already finished web. The opposite position of the heddles is then brought about by depressing the treadle F^1, the odd-numbered warp-threads being thus brought into the lower shed and the even-numbered into the upper. A second pick of filling is then introduced and beaten home with the batten, thus completing a round of all the movements, which are regularly repeated.

The Couper.—While in the production of fabrics interlaced with the plain weave only two different positions of the warp-threads occur, requiring only two harness-shafts, in all other fabrics there are a larger number of different positions of the warp-threads, requiring a correspondingly larger number of harness-shafts; consequently, the arrangement shown in Figure 8 (*pl.* 43) cannot be used, it being replaced by the couper, illustrated in Figure 1 (*pl.* 44). Each harness (a) is connected by a cord with a lever (b, b), which is pivoted on the pin c. A cord passing outside the heddle connects this lever with another (d), twice as long, which is pivoted on the pin e. At f there is secured to the latter lever a cord leading to the treadle g. The same heddle is directly connected by cords and the intermediate lever (h, i) with a second treadle (k). It will be seen that by pressing down the treadle g the heddle a can be raised from the central position, and lowered by pressing upon the treadle k. Now, in the harness as many heddles have to be arranged as there are different positions of warp-threads in the cloth, and as many treadles as there are different positions of filling, each

treadle being connected with all those harness-shafts which are to be raised by its depression by the parts *b, d, f, g*; all the rest, which are to come into the lower shed, directly by the parts *h, i, k*. By varying the "cording" of the treadles a harness of this kind can be so arranged as to be applicable for the production of a large number of different points of intersection and kinds of fabrics. The couper is in general use for weaving twills, satin, and many small figured fabrics, its application being limited only where the number of heddles is too great to be accommodated by the loom and the number of treadles too large to be conveniently accessible to the feet of the weaver. Such is the case in the production of all large figured stuffs—for example, damask, etc.—in which the same position of the warp-thread and of the filling-thread recurs only at long intervals. For this purpose the couper is replaced by the Jacquard apparatus (*pl.* 44, *figs.* 2, 3).

The Jacquard Apparatus consists of the following principal parts: the frame and the perforated board fastened horizontally to the base of the machine, through which are passed the neck-cords of the harness; the hooks and the griffe, with the necessary attachments for lifting the same; the needles, needle-board, springs, and spring-frame; the cylinder, hammer, batten, and catches; and the cards and harness.

Hooks and Needles.—The hooks (*fig.* 5) are made of polished spring wire. The upper ends of the hooks engage with the griffe-bars, and to the crook of their lower ends are fastened the neck-cords of the harness, the small catch serving to keep the hooks in their required position by means of the rest-bar. The needles (*fig.* 4) are also of wire, with a loop on one end and an eye (made by a turn of the wire in the straight part of the needle) between the loop and the point or head. The eye through which the hook is passed is about 3/8 of an inch in diameter, and allows sufficient play for the up-and-down movement of the hook. The point at which the eye is made upon the needle is determined according to the position of the hook which it embraces (comp. *fig.* 3). The needles are adjusted in rows of different heights; the arrangement most used is four, eight (*fig.* 3), or twelve rows high.

The Griffe (*fig.* 9) is a gridiron-shaped cast-iron plate. Each bar (knife) of the griffe accommodates a row of hooks, which when the griffe is down or the machine is at rest stand about 1/2 inch above the bars. The hooks are controlled by the needles, which run horizontally and are kept in position by the needle-springs in the spring-frame (*d*; *fig.* 3). It will be seen that when the hooks are in their natural positions the lifting of the griffe will raise all the hooks; but should any of the needles be thrust back, thus moving the hooks from their vertical positions, they will not be disturbed by the rising griffe (*fig.* 2).

The Cylinder.—The so-called "cylinder" (*fig.* 7) is a hollow four-sided prism. Each side of the prism is perforated with small regularly disposed holes corresponding to the number of the needles, and is also provided with protruding pegs about 1/2 an inch in length, which serve to steady the cards when in contact with the cylinder. The cylinder alone

does not affect the needles, its function being simply to carry on its rotating faces a series of pasteboard cards, which are presented and pressed against the points of the needles by the motion of the cylinder.

The Needle-board (*pl.* 44, *fig.* 8) is a perforated board in which the points (heads) of the needles rest, and by which they are guided to the holes in the cylinder.

The Cards (*fig.* 10) are of pasteboard of sufficient thickness not only to resist the wear caused by the pressure of the needles on those parts not perforated for the pattern, but also to give steadiness to the cards when resting on the pegs of the cylinder. The cards are laced together in an endless arrangement; hence one card follows another in regular rotation toward the needles by the revolution of the cylinder. Figure 1 (*pl.* 45) is a belt-power card-stamper and Figure 2 is a foot-power card-stamper which are used for stamping the Jacquard cards. Figure 3 shows the machine for lacing these stamped cards into an endless arrangement.

The Harness (*pl.* 44, *fig.* 11).—To the lower end of the above-mentioned hooks are adjusted the neck-cords, which are passed separately through one of the holes of the perforated bottom board (*a*). To the neck-cords are fastened the harness-cords (leashes), which pass through holes in the comber-board *b* (a perforated board which guides and keeps the harness-cords in the required positions) and are attached to the heddles. To the heddles are fastened weights (lingoes) and through the eyes (mails) of the heddles the warp-threads are drawn.

Operation of the Jacquard Machine.—In ordinary weaving, as explained on page 152, the warp is divided into two sets of threads, the predetermined alternate division of which is raised and lowered, to enable the weaver to throw the shuttle from his right to his left hand, and *vice versâ*. If, however, a pattern is to be produced either in plain materials or of varied colors, it is necessary, instead of raising and depressing the entire series of threads of the warp in two sets, to raise only such as are required to develop the various parts of the figure; and this must be effected with great exactness, as the formation of the pattern depends upon the position of each thread. The Jacquard apparatus is for the purpose of regulating these movements.

Figure 3, which illustrates one cross-row (containing eight hooks) of a Jacquard machine, gives a clear understanding of the arrangement of hooks (*a*), needles (*b*), griffe (*c*), springs (*d*), with frame for holding the latter, the needle-board (*e*), and the cylinder (*f*). When the machine is at rest, the needle-board (*e*) supports the heads of the needles, which project about ½ an inch toward the cylinder (*f*). The loops of the needles are passed between two bars of the spring-frame (*d*), and are firmly held by the latter, but with sufficient play for the lateral pressure against the springs (*d*). The pin (*o*) is inserted for holding the springs in their places, a pin being required for each vertical row of needles. The hooks embraced by the loops (eyes) of the needles stand vertically, with the small crook of their upper part directly over the griffe-bars. From a study of the illus-

tration it will be evident that when the heads of the needles are pushed laterally, in the direction of the arrow, the hooks will also be moved; hence such of the hooks as are moved out of contact with the bars of the griffe will remain stationary (*pl.* 44, *fig.* 2). From the foregoing explanation it is apparent that by raising the hooks the leashes are lifted, and the latter raise every warp-thread throughout the fabric, forming the shed for interlacing the filling regulated by the design of the cards.

The raising of the hooks in the weave of any given pattern of fabric is actuated by the cards (*fig.* 10). For the warp-threads to be raised holes are punched in the cards which are presented to the needles by the cylinder. This cylinder performs, in addition to its rotary motion, a movement similar to that of a pendulum toward the points of the needles. Any of the needles for which a hole has been punched in the card will penetrate the cylinder; hence the corresponding hooks will remain in their natural positions, and the rising griffe will carry with it the undisturbed hooks, making a shed of the warp-threads attached to their cords. Needles for which no holes have been punched in the cards will be thrust back by the pressure of the cylinder, which forces the corresponding hook back and away from the griffe-bars above, whereupon in raising the griffe they will remain stationary. The thrusting back of the needles compresses the springs, which will again expand as soon as the cylinder leaves the needle-board.

Jacquard Machines.—In Figure 2 (*pl.* 47) there is given the perspective view of a complete single-lift Jacquard machine, while Figure 4 (*pl.* 45) represents the same machine adjusted to the loom. On the longer arm of the lever is a series of holes which regulate the height of the lift by the vertical rod which provides the required movement. The nearer this rod is adjusted to the Jacquard head, the higher is the lift of the Jacquard harness, thus forming the shed. During recent years various modifications in building Jacquard machines have been introduced. The object has been either to simplify designing and card-stamping or to save card-paper and labor for special fabrics, as in the ingrain-carpet machines, the Brussels-carpet machines, etc. Again, the problem of "speed," and consequently of increased production for a given time, in damasks and similar fabrics, has been satisfactorily solved by the construction of the double-lift double-cylinder Jacquard machine (*pl.* 44, *fig.* 13). Another principle for a modification over the single-lift Jacquard machine is to be found in the double-lift single-cylinder Jacquard machine, which has for its object the saving of the warp by operating each individual thread only when required by the changes from up to down, or *vice versâ*, in the design or weave. The previously described auxiliaries for operating the warp-threads either by harness-shafts or the Jacquard machine can be applied to looms in which all the movements are produced by the hands and feet of the weaver, as well as to power-looms; but in the latter certain mechanisms have to be added, which derive the requisite motions from the revolution of a shaft moved by a belt.

The Double-lift Single-cylinder Jacquard Machine (*pl.* 47, *fig.* 3) is a power-loom with Jacquard machine attached. The principle consists in raising the warp-threads any number of times in succession without allowing the shed to close, thus performing the work in nearly half the time and with less wear and tear on the warp.

The Double-lift Double-cylinder Jacquard Machine (*pl.* 46, *fig.* 1) is another kind of Jacquard machine applied to a power-loom. The principle consists in the combination of two separate Jacquard machines. Two hooks (one of each machine) are connected to one leash of the Jacquard harness, and, as each machine is operated alternately, a high speed is attained, which is the purpose of the machine.

Roller-loom.—In the roller-loom (*pl.* 45, *fig.* 5) the raising and the lowering of the harness are governed by two cams, which can be worked with a two, three, four, or five scroll. The cams, which must be at certain distances apart, lower the harness only at regular intervals. The distance separating the cams can be selected for operating each alternate treadle or every third treadle. As the cams lower only the harness, the strapping on the rollers is so arranged that when one of the harnesses is lowered by the cams the roller to which the strapping is tacked has another strap tacked on the opposite side and connected to the harness or harnesses which are required to be raised; for when the roller turns to let one harness down, the harness or harnesses which are attached to the other side of the roller are raised.

The Positive Double-action Dobbie (*pl.* 46, *fig.* 6), the only practical one extant, is here shown applied to the Knowles loom. Its advantages are that it employs no springs, can be run at high speed, requires no additional alley-space, handles warps more easily than any other harness motion, and is suitable for any weight or width of fabrics.

The Heavy Worsted and Woollen Loom, shown in Figure 1 (*pl.* 47), represents one of the most advanced power-looms of the present time. This loom has twenty-five- or thirty-six-harness capacity, 4×4 box, and single or double beam. The main features of this type of machines are a positive box motion, a system of positive and conditional take-up motions, filling stop motion, and equal driving-gears for crank- and bottom shafts, composing a machine on which can be woven every variety of fabric, from the simplest to the most intricate.

Plush-loom.—Figure 7 (*pl.* 46) illustrates a velvet- and plush-loom. It is built with twelve-, twenty-, or thirty-harness capacity and with single box or double stationary boxes at each end, designed to run two shuttles at each pick, or with two or three pairs of drop boxes at each end, arranged to use two shuttles at each pick and call either pair as required by the pattern. The harness motion and the box motion are the same as on the worsted-loom, previously illustrated and explained. In this loom the goods are cut automatically. The take-up motion is positive and accurate in its operation, and the let-off for pile-warp is operated positively from the head motion and controls the length of the pile on the goods.

The New Power Ingrain-carpet Loom is shown in Figure 4 (*pl.* 47). In this loom the journals are controlled either by a cam motion or by a chain motion; the warp is handled with the greatest ease, and either journal is called at will, thus giving a wide range of pattern and design. Should it be necessary to change the shading, it can be done by changing the chain instead of cutting out the warp and redrawing it. The box mechanism in this loom is positive and is controlled by a chain on the same shaft as the journals, and may be used with the chain alone or with the chain in combination with the cards. The motion can be run forward or reversed at will and any box called as desired, thus giving a wide range to the shading facilities of the loom. The take-up motion of this loom is positive, consisting of fluted rolls, and operated by the usual train of gearing, while the goods are wound up on a roll below. The let-off is controlled by the tension of the warp over a rocking whip-roll operated by a cam on the bottom shaft, held by a clamp friction geared to the head of the beam. Two filling motions are used, one on each end of the lay, each working independently of the other, inside the selvedge, so that the breakage of the filling is instantly detected; and these motions are so combined with friction-pulley and brake that the loom is stopped instantly on the pick, and consequently, when filling is replaced, the loom is ready to start without loss of time in finding the pick or setting of Jacquard or box motion. The shuttle-smash protector, which knocks off the loom when the shuttle does not box properly, thus preventing what are known as "shuttle-smashes," a shuttle-check for easing the force of the shuttle as it enters the box, a foot-lever for throwing the lay back when the loom is stopped, making it very easy for the weaver, and the speed at which the loom can be run, together with the features mentioned previously, combine to make this loom a very efficient machine.

Terry-fabrics.—In the manufacture of terry-fabrics in which the pile-threads are raised without the aid of wires, such as Turkish towelling and certain kinds of scarfs used for ornamentation on chairs, bureaus, etc., two warp-beams are required, one to carry the "pile-warp" for forming the loop, and the other to carry the "body-warp" for forming the ground of the fabric. In the process of weaving a terry-fabric the upper or "terry" series of warp-threads is weighted lighter than the lower or "body" series, for the purpose of allowing the loops to be formed on the surface by the lay swinging or being driven fully up to the body of the manufactured cloth after two or more picks of the filling have been shot from the shuttle and only partially beaten up, the picks having in the mean time so tightened upon the upper or terry-warps that the latter are forced with them fully up, thereby forming the pile-loops or terry. As during the entire process of weaving the ground-warp remains tight, the two or more picks will slide upon it in the beating-up. Figures 4 and 5 (*pl.* 46) more clearly illustrate the method of operation. In Figure 5 the picks O represent the edge of the cloth. At the first stroke of the lay the first pick (*l*) is not driven home; at the second stroke the second pick

(*2*) is driven against the first pick (*1*), but no further; but the third pick (*3*) is driven home towards *o* and carries picks *1* and *2* along, pressing them up against the finished edge of the cloth (*o*). The pile or "terry"-warp will thus form the loops *s* as shown in Figure 4 (*pl.* 46). Figures 2 and 3 illustrate a loom and its method of operation in the present style of terry-weaving. In Figure 2 the loom is shown in the position it occupies when partially beating up the filling, and Figure 3 shows the lay forced fully up.

5. FINISHING-MACHINES.

To increase the beauty of their appearance all woven fabrics are subjected to certain operations collectively known as "finishing." Cotton goods, however, require very little finishing to be made ready for the market. Damasks, ginghams, shirtings, etc., after leaving the loom, are only starched, calendered, measured, and rolled. With many woollen fabrics finishing is the main process in their manufacture. Kerseys, beavers, broadcloths, doeskins, tricots, and similar fabrics (technically known as "face-finished" goods), are subjected to many different processes, such as washing, fulling, gigging, drying, dyeing, brushing, steaming, measuring, and folding, before they are ready for market.

Wet-finishing Process: Fulling-mills.—The fulling-mill serves for peculiar manipulation of cloth (woollens) by means of which the run of the threads is concealed and the thickness considerably increased, though at the expense of length and width, thus imparting to the fabric in a high degree the property of retaining warmth. The manipulation consists in a thorough kneading in soap-water, and is based on the property of sheep's-wool, when softened and warmed, to contract spirally and then to "felt" by the effect of the kneading manipulation. The German machine shown in Figure 5 (*pl.* 48) consists of a trough with smooth sides lined with wood, the bottom being semicircular. In this trough a block—the so-called "beater" or fulling-stock—oscillates to and fro like a pendulum, receiving its motion from the horizontal driving-shaft by means of short slide-rods. The fabrics to be fulled, being thoroughly moistened and irregularly folded together, are placed in the trough on both sides of the beater, and receive the above-indicated manipulation by receding before the beater and after mounting on the inner side of the trough falling again in front of the beater, thus executing a slow circulation. Only fabrics of sheep's wool can be fulled, but similar machines may be used for washing linen and cotton goods. Figure 2 (*pl.* 49) illustrates a cloth-washing machine, and Figure 1 a fulling-mill. Both are of the latest American make.

Gig.—Cloth is "gigged" for the purpose of raising the nap evenly over the fabric, or, in other words, to produce a velvet-like face and back. The nap is raised either by means of the teasel (*pl.* 48, *fig.* 1, the dried flower-head of a plant, *Dipsacus fullonum*, specially cultivated for this purpose), or by means of fine steel wires. The teasels are set side by side in rows one, two, or three high, according to their size, in wooden or iron

frames, technically known as "slats," which, after being filled with the teasels, are fastened to the periphery of the main cylinder of the gig. The position of the slats can be reversed so that two portions of the teasels may be utilized. Figure 3 (*pl.* 49) illustrates an "up-and-down" gig, by which the direction of the running of the cloth can be changed, and which is so arranged that there can be one or two applications of the cloth to the cylinder. In operating the machine the cloth winds on small rolls, which lie against the cloth-beams, and can therefore be handled on the rolls. The operator can reverse the nap by allowing the cloth to run entirely on the lower roll, and then by taking it from the lower cloth-beam and putting it against the upper cloth-beam.

The Wire Napping-machine (*pl.* 50, *fig.* 2) consists of a skeleton cylinder on whose circumference revolve fourteen card-rolls in their respective bearings, while suitable frames and guide-rolls are provided to carry forward the cloth. As the cylinder revolves in the direction in which the cloth travels, each one of the card-rolls comes in contact with the cloth at five different points. If, however, these rollers were not subjected to some action other than the mere revolution of the cylinder, there would be no napping, for as the cloth presses upon the cards and the cylinder carries them forward the friction of the cloth causes the rolls to revolve on their own axes in a direction opposite to the motion of the cylinder; consequently, as the points of the cards are bent in the direction in which the cylinder revolves, they have no action upon the cloth. But by an arrangement of cones, pulleys, and belts this reverse action is controlled at the will of the operator, and may be varied almost indefinitely.

Cloth-drying Machine.—As during the process of gigging the cloth is kept wet, it must be dried after the nap is sufficiently raised. For this purpose there is employed a machine known as the "cloth-dryer" (*pl.* 49, *fig.* 4), which when in operation is closed up with the exception of a sufficient opening for the entrance and the exit of the cloth. The cloth is drawn into and guided through the machine by two endless chains, one on each side, as seen in the illustration. In these chains are inserted medium-sized steel pins, which catch into the selvage of the cloth and hold it taut, during its travel in the machine, between pipes heated by steam. The cloth, which is run in at the upper front of the machine and leaves at the bottom of the rear, will, by its own weight and on account of its dry condition, liberate itself from the pins when leaving the dryer.

Hydro-extractor.—For the removal of the greater portion of adhering water the cloth, if very wet when leaving the gig, is first put into a hydro-extractor, which consists of a cylindrical kettle of sheet copper fastened to a vertical spindle. The sides of the kettle are perforated with numerous small holes. The motion is imparted by two horizontal driving-shafts, revolving in opposite directions, which by means of friction-wheels cause the spindle to rotate at great speed. The frame in which the driving-shafts rest is screwed to a trough enclosing the kettle. By placing the wet fabrics in the kettle and revolving the latter at great speed the cen-

trifugal force produces the well-known effect of pressing the fabrics against the sides of the kettle and forcing through the holes in the sides the adhering water, with the exception of a fractional portion, which has to be removed by evaporation. The water collecting in the trough enclosing the kettle runs off constantly through an aperture on one side. Figures 6 and 7 (*pl.* 38) illustrate two styles of hydro-extractors. Figure 6 shows an improved centrifugal hydro-extractor. This machine is extensively used by silk-dyers. The extractor has a vertical engine attached to the side, which operates the vertical spindle fastened to the cylindrical kettle by means of cone-pulley friction. Figure 7 is another form of machine, operated by means of a direct-acting steam-engine, which is clearly visible in the illustration. This machine is in general use with cotton- and woollen-manufacturers, and is capable of the heaviest work.

Dry-finishing Process: Brushing-machine.—The cloth, after leaving the drying-machine, is run through the brushing-machine, though special fabrics—such as chinchillas, whitneys, montagnacs, etc.—which require no brushing or whose face would be injured thereby are not brushed. Figure 5 (*pl.* 50) illustrates a brushing-machine and its mode of operating.

The Shearing-machine, commonly called the "shear" (*pl.* 48, *fig.* 2), receives the cloth after it has left the brushing-machine and gradually evens the nap raised by the gig. The cutting is done by quick-revolving sharp steel knives, called "blades," which make about one thousand revolutions per minute.

Pressing- and Measuring-machines.—After the fabric is finished on the shear it is again brushed and forwarded to the pressing-machine. Figure 1 (*pl.* 50) is a single-bed press; Figures 3 and 4 (*pl.* 48) show a double-bed press; Figure 3 shows the press with pressure applied, and Figure 4 shows it with pressure removed. After the cloth is pressed it is measured and then rolled, when it is ready for market. Figure 3 (*pl.* 50) illustrates a cloth-measuring machine, and Figure 4 represents a combined cloth-measuring and winding machine.

6. TWISTING-FRAMES AND BRAIDING-MACHINES.

Plate 51 exhibits typical machines for combining two or more separate filaments into strong thread-like products (thread, cords, ropes, cables, etc.). Such a combination can be effected either by twisting, by plaiting, or by braiding.

Ropemaker's Wheel.—The simplest contrivance—capable also of being used for spinning—is the ropemaker's wheel, a typical arrangement of which is shown in Figure 1. It contains a number of spindles, whose outer or free-lying ends are bent in the form of hooks and receive a rapidly revolving motion by suitable mechanism. In the arrangement shown on the Plate the motion is provided by means of a pulley actuated by a cord. By drawing this cord the workman, who walks backward in spinning and twisting, sets the pulley in motion, while with the earlier

wheels a separate workman was required for turning. In spinning with this apparatus the workman draws a few fibres from a bundle of raw material—for example, tow—and after twisting them to a thread fastens the latter to one of the hooks on the wheel. He then moves slowly backward from 16 to 20 inches per second, the motion thus imparted to the wheel drawing from the bundle of material new fibres, which are suitably twisted by the rotation of the hook. If, now, two or more strands thus obtained are to be combined into a stronger thread (twine, cord, etc.), their ends are secured to another hook, revolving in an opposite direction, and twisted together, the other ends being generally suspended to a hook resting on a movable frame. Experience has shown that by choosing for the combination of the separate strands a revolving motion opposite to that applied in their formation a more intimate intertwining is effected.

Ropemaking-machine.—For working on a large scale the wheel is replaced by the ropemaking-machine, one type of which is shown in Figure 2 (*pl.* 51). By the machine represented in the Figure three cords, consisting of three separate threads each, are simultaneously twisted together, and are then further combined by twisting into one cord. All the movable parts of the machine producing this result are grouped around a horizontal spindle, to which a revolving motion is transmitted through the driving-pulley on the left of the machine. This spindle carries three frames, set at equal distances apart, in which are placed smaller frames, each provided with three yarn-bobbins, so that they can be turned. Inside each of the smaller frames the three threads coming from the bobbins are combined into one thread through an eye in the revolving axis, and at the same time are helically twisted together. The latter result is produced by the smaller frames, which may be considered as a reservoir for the thread material. These frames while revolving around the principal spindle have an independent motion around their own axis, imparted through a spur-wheel placed concentrically to the principal shaft, but fastened to the frame, on which three smaller intermediate wheels drive the above-mentioned frames. The three cords thus formed are finally combined in a common central discharge aperture on the end of the principal shaft, and the thicker cord here formed is slowly drawn off by passing between three revolving rollers, the two upper of which are pressed against the lower one. All large rope-machines must be provided with a winding-apparatus.

Thread-twisting Frames.—In many cases a simple doubling is sufficient for the production of a twisted fabric, such as sewing-thread, knitting-yarn, warp- or filling-threads for weaving, etc., for which the simple duplication of the apparatus may be advantageously applied. The upper portion of the twisting-machine is a frame of laths, on which the bobbins, filled with single threads, are placed. The threads coming from three, four, or five bobbins are guided to one eye and then pass between a pair of rollers, which receive a uniform motion from the driving-shaft and deliver the doubled threads at a corresponding rate. The threads are twisted by a revolving

flyer, the arrangement of which has been already explained in describing the water-frame (p. 143), and are finally wound in regular convolutions on bobbins.

Bobbin-frames (*pl.* 51, *figs.* 4, 5) are closely allied to thread-frames. The combination of several threads, however, being, as a rule, omitted, only the winding process remains, the object of these machines being to wind on bobbins the customary commercial skeins or hanks of yarn intended for weaving purposes. Of these bobbins there are two kinds—movable bobbins (pirns), which render the unwinding possible in a direction vertical to the axis, requiring, therefore, the rotation of the bobbins; and fixed bobbins (cops), which are stationary during unwinding, the drawing off of the thread being effected in the direction of the axis. The former are used for the preparation of the warp and the latter for the preparation of the filling. With the pirns the separate spiral convolutions form cylindrical layers on a wooden spool, while with the cops the separate convolutions form conical layers, which are superimposed on the conical end of the bobbin.

This explains why a different arrangement is required for the warp spooling-machine (*fig.* 4) and the filling spooling-machine (*fig.* 5). In the former the threads pass from the reel over a rail moving slowly up and down to the quickly revolving bobbins set on vertical spindles; in the latter the threads pass through a vertical slit of a stationary hollow cone, in which is set the revolving bobbin, so as to touch the cone with its conical end and ascend as the winding progresses. The bobbin must, therefore, be so connected with its spindle that it is forced to participate in its revolving motion, while at the same time it is capable of moving upward.

Ball-winding Machine.—The finer products (sewing-thread, twine, knitting-yarn, etc.) being frequently demanded made up in regular balls, a ball-winding machine (*fig.* 3) is included. The cord to be made into a ball is passed through the hollow axis of a fork-like revolving fly and through an eye on one arm of the fly to a spindle, which simultaneously executes two motions—a slow rotation around its horizontal axis and a still slower oscillation around a vertical axis, the latter motion causing the helical convolutions produced to change their angle of incidence, whereby the necessary firmness of the whole is effected. The ball-winding machine shown in the Figure is worked by hand, three balls being made at the same time.

The Braiding- or Plaiting-machines effect an intertwining of the separate threads similar to braiding by hand. The threads are separated into two groups, those of the one group running like a right-hand spiral and those of the other like a left-hand one. Each thread of the one group passes alternately over and under a thread of the second group; so that here, upon a cylindrical surface, a similar intertwining of the threads takes place as between warp and filling in weaving. The resulting fabric forms a flexible tube, which, by means of a suitable number of threads loosely placed together, can be filled with a core. It is also possible to

braid over solid bodies, or cores; as, for example, whip-handles, buttons, etc. The threads to be intertwined are wound on bobbins so set that they can be turned on special tubular bobbins, which by means of stelliform revolving drivers are pushed forward on two undulatory endless tracks, alternately crossing each other and returning. That all the threads may enter the braiding with the same constant tension, they are passed, as shown in Figure 6 (*pl.* 51), through the eye of a weight placed in the hollow part of the bobbin, the uniform closeness of the braiding being furthermore secured by the uniform drawing away of the braided cord by means of two revolving rollers, around which it passes, and is finally wound in regular convolutions on a bobbin.

7. KNITTING-FRAMES.

The Stocking-frame, an outcome of the method of knitting by hand, was invented in 1589 by the Rev. William Lee, a native of Woodborough, near Nottingham, England, and a graduate of Cambridge. It uses, as in hand-knitting, only one thread to produce a flexible fabric with an extended superficial area. The thread is curved in definite layers, called "meshes," which resemble two letters S standing symmetrically to each other, and which complete the fabric by intertwining (*pl.* 52, *fig.* 1). The thread, therefore, is not drawn in a straight line, but is disposed in curves in serial order throughout the fabric. On account of the elasticity of the thread its form readily re-establishes itself when drawn out of shape, and thus the fabric, being elastic, is better adapted for close-fitting garments than are other tissues.

The Needles.—For the production of the meshes, needles (*fig.* 2) with long hooks and thin pieces of tin, called "sinkers," provided with several notches, are required, the number of both corresponding to the number of meshes in the width of the fabric. While in hand-knitting each new mesh is separately formed by drawing the thread, in the form of a loop, through the one previously formed, in working the stocking-frame an entire row of meshes is produced at one time after the following preparatory manipulations (*fig.* 2): The knitted part of the fabric is drawn back upon the needles by the arches in the sinkers, and the thread, being laid lengthwise over the needles and beneath the ribs of the sinkers, is pressed, in the form of loops, between the needles by depressing each sinker. These loops are pushed in front under the hooks of the needles, while the previously formed meshes remain behind them. The barbs of the hooks are forced downward into the grooves in the stems of the needles by means of a bar, called the "pressure-bar;" so that finally the old meshes can be pushed upon the hooks and from the needles. They remain then suspended in the new loops, thus forming new meshes.

Couler-knitting.—This formation of meshes with but one thread is termed "couler"-knitting (from the French *couler*—that is, pushing the sinkers between the needles). By another method of knitting, invented in 1769, not one thread only, but a number of parallel threads—a so-called

"chain" or warp—is used, the threads being united by forming meshes. This mode of working is termed "chain"- or "warp"-knitting. The machines for couler-knitting are the hand- or stocking-frame, the flat and the round power-frames. A so-called "French round frame," which contains the needles lying horizontally and radially upon an annular ring, is shown in Figure 5 (*pl.* 52). The leads are in separate boxes, the so-called "mailleuses" or mesh-frames. The illustration shows the best examples of these mailleuses (*mailleuses obliques*).

Lamb's Knitting-machine.—For about thirty years another method of forming meshes has been known, in which are used self-acting needles (*fig.* 3), the short hooks of which can be closed by placing upon them a movable arm (tongue); so that the pressure-bar is omitted The meshes are formed in the manner of crocheting by the needles passing separately through the old meshes and catching the thread with the hook, drawing it, in the form of loops, to new meshes through the meshes last made. This is the principle employed in Lamb's knitting-machine (*fig.* 8), an American apparatus invented in 1866, which is now in general use. The self-acting needles lie in two straight parallel rows, widening and narrowing being accomplished by increasing or diminishing the number of needles in action. Their lower ends, bent to a hook, are caught by the grooves formed by three plates (*fig.* 6) and are raised and lowered, whereby the meshes are separately formed one next to another. With small jointed levers (*fig.* 6) the position of the groove-plates can be changed so that the needles are more or less depressed and work loose or close. The name "knitting-machine" has been applied to this device because it is possible to produce with it fabrics, especially stockings, in nearly the same manner as by hand-knitting—that is, regular, round, and without seam. This term, however, has been also applied to other machines, working flat, like the hand-frame, provided they can be readily handled and produce stockings of a regular shape—that is, without cutting. Figure 7 is the guide and tension.

Hinkley's Knitting-machine (*fig.* 9) can produce only flat fabrics, like the hand-frame. It is really not a knitting-machine, but a single-thread, chain-stitch sewing-machine, which by means of a sewing-needle draws the thread, in the form of a loop, through the mesh last made, this loop being held by a catch and finally suspended as a new mesh upon a comb. The comb, which corresponds to the row of needles of the hand-frame, contains the new meshes separately alongside one another while going with its teeth past the sewing-needle. Machines for knitting are either hand-machines or power-machines. The first kind have their needles placed either in a straight row or in a circle (*fig.* 4), or only one needle is used (*fig.* 9). Power-machines are built either for producing a plain flat strip of fabric or for circular ribbed stuff. A machine for producing the latter fabric is shown in Figure 10. Figure 4 exhibits an American stocking-machine with belt and pulleys for operating it by power, but which, minus the power attachment, is usually worked by hand. (E. A. P.)

8. Sewing-Machines.

The idea of mechanical sewing was originally conceived in England, though the first practical sewing-machine was undoubtedly produced in America.

Saint's Sewing machine.—In 1790, Thomas Saint, an English cabinet-maker, was granted a patent for "an entire new method of making and completing shoes, boots, spatter-dashes, etc.," and, though he may have constructed only an experimental machine, it yet embraced many of the germs of the perfected sewing-machine of the present day. It possessed (1) a horizontal supporting surface for the cloth, to resist the thrust of the needle; (2) an overhanging arm, to whose outer end was attached (3) a vertically reciprocating straight needle fed by a continuous thread from a spool placed at the top of the arm; and (4) a mechanism by which the material was moved automatically after each stitch. The inventor conceived the idea of sewing a seam without passing the entire needle through the material, but by pushing through it a loop, to be so held open by a hook as to receive the loop of the succeeding stitch. This interlooping or enchaining of stitches resulted in the production of what is known as the "chain-" or "single-thread" stitch (p. 172). The needle employed by Saint was so forked at its lower end as to span the thread and push it through a hole previously made by an awl in the material; the tension of the thread was adjusted by tighteners above and below. To Saint, therefore, must be accorded the honor of devising a connected piece of machinery, however crude it may have been, which was the prototype of the modern sewing-machine. An English patent in 1807 is also the first to show an automatically operating contrivance with an eye-pointed needle to carry a thread through the material to be connected.

Thimonnier's Sewing-machine.—In 1830, Barthélemy Thimonnier, a humble French tailor, patented a sewing-machine which was so far successful that in 1831 he was made a partner of the firm of Germain Petit & Co., and set up on Sèvres street, in Paris, a workshop where eighty machines, rudely constructed of wood, were in use for making army-clothing. At this time workingmen were hostile to every kind of new machinery, and these sewing-machines were destroyed by a mob, as the Jacquard loom and Hargreaves's spinning-jenny had been years before. Thimonnier escaped with his life and again set to work to improve his machine, and was so far successful, notwithstanding the privations under which he labored, that in 1845 his apparatus was run at the rate of two hundred stitches per minute, whereas the machine of 1830 was unable to make more than one stitch at each movement of the treadle. In 1848 he applied for an improvement patent for his machine, which he called "consobrodeur," but, the French revolution of that year having stopped his business, he went to England, where, after staying a few months, he sold his patent to a Manchester firm and returned to France. Exhausted by thirty years' struggling and suffering, he died penniless at Amplepuis in 1856.

Thimonnier's machine (*pl.* 53, *fig.* 1) comprised a horizontal bed for the support of the material; an overhanging arm, which was constructed as a sliding frame, and which was alternately depressed and returned by a treadle and spring; and a vertical needle with a hooked or barbed point. The hooked needle penetrated the cloth and caught a lower thread, by means of a thread-carrier and looper, from an ordinary spool, and in rising drew a loop of thread with it to the surface of the material and within a nipple sleeved upon the stem of the needle, the nipple resting upon the goods during the descent of the needle and rising when the latter cleared the goods. After the loop was drawn up, the cloth was moved by hand the length of a stitch, and the needle was again thrust downward through the material; in its next ascent it brought up a loop through the one previously formed, thus producing upon the surface of the stuff the chain of the stitch, unlike the Saint machine, whose chain was on the under side of the cloth. Thimonnier's machine was patented in the United States in 1850.

In 1843 there was patented in the United States by B. W. Bean a form of sewing apparatus which is now known as the "running-stitch" machine. The needle, pointed at one end and with an eye at the other end carrying a short length of thread, was held stationary between toothed rollers, and the material, in convolutions, was fed upon the point, along the body, and off the heel of the needle upon the thread, the operator pushing the fabric back upon the thread as in hand basting. There have been patented in the United States and in England a number of varieties of this machine, which are used principally for sewing together the ends of materials to be bleached, dyed, or printed (see p. 172).

Hunt's Sewing-machine.—In 1833, Walter Hunt of New York invented a sewing-machine with a curved eye-pointed needle operated by a vibrating arm and penetrating the cloth, and with a shuttle that passed through the loop made by the needle-thread, and by drawing it up on one side of the cloth making what is known as the "lock-stitch." The material was suspended vertically between clamps moved automatically after each stitch; but the machine could sew a seam only the length of the clamps without being stopped. Moreover, the seam had, substantially, to be parallel with the actuating mechanism of the clamps. Hunt laid aside his machine, which was destroyed, and was forgotten until 1854, when he applied for a patent, which was refused him on the plea of abandonment. The main features of Hunt's invention had, however, been patented in 1846 by Elias Howe, thus anticipating by eight years the application of Hunt, who by inattention to the value of his apparatus lost one of the greatest opportunities of the nineteenth century.

Howe's Sewing-machine.—The ingenious contrivances above described illustrate substantially the progress of the art of machine-sewing up to the date (1846) of the invention of the machine by Elias Howe, whose name is indissolubly associated with the history of the sewing-machine. From the foregoing it will be seen that the invention was a development,

and not an inspiration. Sporadic attempts were made to solve the problem of mechanical sewing and to embody it in a successfully-operating machine. The greatest advance was the lock-stitch of Hunt, but, as above stated, it remained for Howe to be declared the inventor.

As originally made, Howe's machine (*pl.* 53, *fig.* 4) consisted essentially of a curved and grooved eye-pointed needle carried at the extremity of a vibrating arm, a shuttle with its point at one side of its axis and carrying a bobbin or cop, and a so-called "baster-plate," composed of sharp-pointed wires projecting laterally, comb-like, from a thin curved metallic plate, which was actuated intermittingly by a toothed wheel engaging with holes in the plate. It employed two threads, one of which was projected through the material, while the other was carried by the shuttle. The grooving of the needle was devised so as to receive and protect the thread from being broken by the rapid movement of the needle through the fabric. The point of the needle being driven about three-fourths of an inch through the material, the needle-thread, extending from the last stitch to the eye of the needle, formed the chord of the arc of the needle, and through the space thus formed the shuttle was projected by reciprocating drivers, so that when the needle was withdrawn the two threads were left interlocked at the point where the needle perforated the cloth. Before the needle penetrated the goods, a sufficient length of thread was drawn from the spool to afford the requisite slack to the needle and needle-thread for the passage of the shuttle between them. This slack thread was held up by a lifting-pin, which prevented the entanglement of the thread under the needle-point. The tension of both the needle- and the shuttle-thread was so adjusted as to cause the stitch to have the same appearance on both sides of the fabric, the interlocking point of the threads being drawn within the material. The edges to be united were vertically impaled on the wires of the baster-plate, which after each stitch was moved by the above-described mechanism. The length of the seam that could be sewed without stopping the machine was the same as that of the baster-plate; and when the latter had passed its full extent under the needle, it was necessary to stop the machine, remove the cloth, return the plate to the first position, and readjust the cloth. The latter was retained on the wires by means of an adjustable plate, and the outer side of the shuttle-race presented a bearing surface for the cloth, to resist the horizontal thrust of the needle.

Howe's early career was a struggle with misfortune, but his indomitable energy finally brought him financial success. Soon after he received his patent one of his machines was sold to William Thomas, a London corset-maker, who made Howe a proposition to come to London and adapt the machine to the manufacture of stays. The offer was accepted, and in 1847 he sailed for England, where, after remaining but a short time in the employ of Thomas, he was reduced to such extremes of poverty that he pawned his American patent-right to obtain means for returning to New York, where he arrived in 1849. During his absence in England sewing-

machines had come into use in the United States. Against the infringers of his patent Howe instituted suits, which were sustained, and henceforth he gathered a golden harvest. He admitted at the time of his application for a second extension of his patent (1867) that he had received $1,185,000 from his invention.

The feasibility of mechanical sewing being demonstrated by the Howe machine, there followed in rapid succession other inventions of considerable ingenuity and excellence.

Batchelder's Machine.—In 1849, John Batchelder produced a machine which was the first to combine a horizontal support for the cloth, an eye-pointed needle, and a continuous feed. The supporting surface for the material consisted of an endless belt with projecting pins, carried on rollers, which moved intermittingly and put in motion the fabric after each stitch. A seam of any desired length could be sewed, but the pins of the feed-belt prevented the moving of the cloth in any direction except with the feed.

Blodgett-Lerow Machine.—Following the Batchelder machine a patent was granted the same year to S. C. Blodgett and J. H. Lerow for a rotary shuttle, or one which drove the shuttle in a circular race with each stitch. The needle descended through the material and then rose slightly, to form a loop of the needle-thread; the shuttle entered the loop and the needle again descended a little, while the shuttle passed through the loop, whereupon the needle ascended above the cloth. This movement is known as the "dip" motion.

Wheeler & Wilson Machine.—One of the most ingenious inventions of this period, and the next in historical importance, was that devised by Allan B. Wilson. His first machine employed a straight eye-pointed needle and a shuttle reciprocating in a curved race, but in subsequent patents (1851–52) he dispensed with the shuttle and substituted for it the disc-bobbin and the rotary hook, which catches the loop of the needle-thread, expands it, and passes it around the bobbin, within which is wound the lower thread, leaving the latter in the loop of the needle-thread. The rotating hook was a new departure from all former methods of sewing, and it effected by rotary motions what had previously been performed by reciprocating motions, while at the same time the speed and the efficiency of the sewing-mechanism were increased. The most important feature of the invention, however, was the "four-motion" feed. This feed-mechanism is so constructed that in rising and falling the material is intermittingly caught, fed forward, and released, and, moreover, allows the cloth to be turned, twisted, or moved by the operator in any desired direction between any two successive stitches. This feeding device is used in nearly every machine now constructed. Figure 14 (*pl.* 54) exhibits an early type of the Wheeler & Wilson machine, and Figure 15 one which embodies the latest devices.

Singer's Machine.—In 1850, Isaac M. Singer of Boston saw in operation a Blodgett machine whose construction he concluded could be

improved. His idea was to make a machine which would embody a horizontal cloth-plate, a yielding presser-foot, to bear upon the cloth, a vertically reciprocating straight needle, and, placed below the cloth-plate on a horizontal axis, a feed-wheel with projecting pins, to engage the cloth and move it forward with each stitch. He constructed a model machine in eleven days, but it would not sew and was pronounced a failure. It was remarked, however, by one of the promoters of the enterprise that the loops of the thread were upon the upper surface of the cloth, when it instantly occurred to Singer that the adjustment of the tension of the needle-thread had been forgotten. After the tension had been adjusted five perfect stitches were made, when the thread snapped. But that was sufficient: it betokened the ultimate success of his invention; and this original (*pl.* 53, *fig.* 5), which was subsequently much improved, was practically the first machine used as a substitute for human fingers in sewing.

Singer's inventions contributed to the sewing-machine the following original devices: (1) A rotating shaft in an overhanging arm, a crank-pin or roller, and a heart-shaped cam, to give positive action to the needle-bar; (2) a pressure-foot at the end of a vertical rod, to hold the material down upon the feeding device, and so adapted by means of a spring as to yield to the thickness of the fabric; (3) a rotating feeding-wheel, which projected through and above the horizontal cloth-plate; (4) a friction pad, to prevent the kinking or twisting of the thread under the point of the descending needle; (5) a spring guide upon the shuttle, to control the slack of the shuttle-thread and keep it from being caught by the needle; and (6) he gave to the shuttle an additional forward movement after it had momentarily stopped, to draw the stitch tight, this being effected while the feed moved the cloth in the reverse direction and the needle completed its upward motion, so that the two threads were simultaneously drawn. Singer was also the first to construct a device to lay an embroidering thread upon the surface of the cloth, under the needle-thread, and the first to invent a machine for ruffling. Attachments for braiding, embroidering, etc., are now adapted to every popular machine (p. 173). Figure 13 (*pl.* 54) represents an improved machine with oscillating shuttle.

The Grover & Baker Machine was invented in 1851 by William O. Grover and William E. Baker, and was patented in 1852. It employed two reciprocating needles. The upper or vertical one was a straight eye-pointed needle, which passed through the material and made a loop, through which the lower curved and eye-pointed needle passed horizontally, forming a second loop, the needles so operating as to interlock the two loops, thus making the double-looped stitch, which, though elastic and strong, was objectionable on account of the ridge left on the interlacing side of the cloth. Later the machine was somewhat modified: the vertical needle was curved and was carried by a vibrating arm, and the looper or lower needle was made to operate by the special mechanism now common in the machine.

Willcox & Gibbs Machine.—In 1856, James E. A. Gibbs, a Virginia farmer, devised an improved chain-stitch machine which, under the subsequent patents of C. H. Willcox and others, is popularly known as the Willcox & Gibbs sewing-machine (*pl.* 53, *fig.* 6). It employs the eye-pointed needle and an ingenious rotating hook, which revolves beneath the cloth-plate. The needle is carried by a reciprocating bar actuated by a vibrating lever connected by a link with an eccentric on the main shaft. As it rotates, the hook, which is at the forward end of the main shaft, catches the loop of the needle-thread, expands it, and holds it expanded while the feed moves the cloth. When the needle descends through the first loop, the point of the hook is again in position to catch the second loop, at which time the first loop is cast off and the second is drawn through it, the first loop being drawn up against the under surface of the cloth, thus forming a chain-stitch. Subsidiary devices are attached for regulating the thread-delivery, the feed, the tension, etc.

Sewing- and Buttonhole-machine.—Figure 16 (*pl.* 54) represents a sewing-machine with which is combined the important feature of a buttonhole-machine without the use of attachments or complicated mechanism. The combination is so effected that neither branch of work interferes with the other. It is adapted to use one or two needles and will make at one operation two seams, either straight or zigzag (*fig.* 8), the latter seam being produced by the same device that is employed in making the buttonhole stitch (*fig.* 8).

Needles.—Sewing-machines employ either straight or curved eye-pointed needles. The straight needle, which is fixed in a vertical bar and reciprocates in a straight path (*fig.* 1), is the least likely to bend or spring when in operation, in which respect it has the advantage over the curved needle, and must ultimately take the place of the latter. The curved needle oscillates on an axis, and it must be so set that its curve shall exactly coincide with the arc in which it moves, otherwise it will draw the material, and in crossing seams be liable to spring and to break.

Shuttle and Rotary Hook.—Externally the ordinary sewing-machine shuttle is shaped, approximately, like the half of a cigar cut lengthwise, with a cavity in its flat side for the bobbin containing the lower thread (*pl.* 53, *fig.* 16). Of this form of shuttle there are various modifications. The shuttle rests in a guide-way or track, called a "shuttle-race," into which the needle descends, so that the point of the shuttle may enter the loop of the needle-thread. At first the race-way lay parallel with the line of the seam, but in the Blodgett-Lerow patent the race-way was circular, and in later forms it is at right angles to the feed, by which the transverse reciprocation of the shuttle greatly improves the evenness of the seam. Various contrivances have been devised for driving the shuttle in the race, but the preferred form of mechanism is the shuttle-cradle or carrier, which is shaped to receive the shuttle within it and to move with and pass the shuttle through the loop of the needle-thread. An improved device for passing the lower thread through the needle-thread loop is a

rotating hook which is so bevelled and notched as to seize the loop, expand it, and pass it around a stationary discoidal bobbin containing the under thread (*pl.* 53, *figs.* 13, 14). Intermediate between the shuttle and the rotary hook is the Singer oscillating shuttle (*fig.* 15). The latter is hook-shaped, similar to the preceding, and carries within it a circular bobbin. The shuttle is driven by an oscillating driver in an annular raceway, but, instead of revolving completely, it is moved in an arc of only 150°, or so far as serves to catch and clear the upper thread.

Feed.—For moving the material intermittingly past the needle there have been employed various devices, most of which, in describing the development of the sewing-machine, have been noticed in the preceding pages. In popular makes of machines the feeding mechanism is for the most part of the "four-motion" class, in which a notched bar rises against the cloth, moves it forward horizontally the length of a stitch, falls, and returns to its original position. The direction of feed may be either in a line parallel with the eye of the needle or at right angles to it. In the latter method the thread, after passing through the eye of the needle, is turned about the needle, which produces more friction upon the thread than the first plan.

Stitches.—The perfection of mechanical sewing necessarily depends on the stitches produced in the seam of the fabrics to be connected. The different inventions patented in the United States are capable of forming upward of sixty-five distinct stitches, employing from one to three threads. These, however, may be reduced to three varieties—namely, the simple chain- or crochet-stitch, the double chain-stitch, and the lock-stitch. The last-named is the most popular of these stitches and requires the smallest amount of thread.

Single-thread Stitches.—The earliest attempts to produce a seam mechanically were in imitation of hand-sewing. In 1755, Charles F. Weisenthal devised a double-pointed needle with a central eye (*pl.* 53, *fig.* 2) for the production of the ordinary basting-stitch made by hand. In this contrivance the needle was pushed through the material, then guided through the stuff in another place in the opposite direction, being alternately caught by two nippers, one on each side of the piece to be united. This mode of operating is now utilized in Heilmann's embroidery-machine, which will be considered farther on. By another method the needle penetrated several convolutions of the undulated material (*fig.* 3). For producing the latter form of basting seam Figures 7 and 8 exhibit two machines which are much used in finishing- and print-works for stitching together the ends of separate pieces of goods. Two cog-wheels gearing into each other catch and gather the fabric into many regular folds, which are pushed upon a long threaded needle. The needle is fastened to the frame and can be brought close to the gear-wheels by means of a groove in their peripheries. By detaching the needle from the frame and drawing it completely through the folds the thread is drawn after it, and the united ends of the stuff are then straightened.

Single Chain-stitch.—Figures 2 and 3 (*pl.* 54) give an accurate illustration of the single chain-stitch. Each stitch of the thread forms a loop, which encloses the loop of the succeeding stitch. By pulling the thread on one end (to the right in *fig.* 3) a very easy separation of the two layers of stuff is possible (*fig.* 2)—a result that is desirable in some cases of domestic purposes, but that is objectionable as regards durability. The ordinary method of forming this stitch by a revolving hook is shown in Figure 12 (*pl.* 53). At *a* is seen the formation of a loop, caused by the descent and the beginning of the return-stroke of the needle, which has on one side a shallow groove, so that in withdrawing the thread is retained in the stuff by the friction, and thus forms a loop. Into this loop the point of the hook, which rotates on a horizontal axis, catches, and during its subsequent rotation of 180° the needle retrogrades entirely, the loop is completely drawn over the hook, and the material is simultaneously pushed forward the length of the stitch. The loop formed has then the shape represented by *c*, which remains for a moment so far open that the succeeding descent of the needle passes through it. With the completion of the revolution of the hook the loop leaves the latter and encloses the new loop made by the entering point of the hook, the intertwining of the thread thus effected producing the so-called "open-mesh" stitch in crocheting. This method of forming the single chain-stitch seam is peculiar to the Willcox & Gibbs machine (*fig.* 6).

Figure 9 exhibits a single chain-stitch machine in which an oscillating hook or needle and a feeder are made of a single strip of sheet metal. The needle is an attenuated extension of the metal strip, which is bent back on itself and forms an elastic spring. The feeder is formed by a lateral projecting strip with a forked end, which is bent over, so as to produce a spring-like curvature with its forked end resting on the main piece. Holes are drilled in the needle-holder and in the needle-point, through which the thread is rove. On pressing the needle-holder down the needle is pushed through the cloth; the needle, on rising, leaves a loop on the under side of the cloth, and the feeder, having been forced back by the needle in its downward passage, advances and moves the cloth and the loop along for the succeeding stitch. The next time the needle comes down it passes through the loop just formed, and so on continuously. The practical availability of such a simple machine unfortunately ceases at a certain point.

Double Chain-stitch.—In the double or two-thread chain-stitch the upper thread in each stitch forming the loop is drawn completely through the cloth, and is secured on the lower side by a second thread, which not only encompasses the loop, but also penetrates it (*pl.* 54, *figs.* 6, 7). This stitch, which is original with the patentees, Grover & Baker, gives a very durable seam, and by using an especially heavy lower thread a beautiful ornamental stitch. The production of the double chain-stitch, however, requires the greatest amount of thread.

Lock-stitch.—The larger number of sewing-machines employ the lock-

stitch (*pl.* 54, *figs.* 4, 5), for whose production two threads are required; one enters the stuff from the upper side and the other from the under side, the upper thread running below the lower and the lower above the upper, the crossing or interlacing thus effected being drawn up into the fabric. If the tension of the lower thread is stronger than that of the upper one, this locking does not take place in the centre of the thickness of the material, but on the lower side, as shown in Figure 4, in which case the lower thread can be drawn out with comparative ease. The uniform tension of both threads is, therefore, the principal condition for the production of a good seam. The chief advantage of the lock-stitch is its great durability and its uniformly beautiful appearance on both sides of the fabric.

Two methods are employed for passing the lower thread through the loop of the needle-thread, the first of which is by means of a shuttle carrying a bobbin and working in a race, and the second that of a rotating hook formed on the circumference of a disc or wheel about an inch in diameter. The formation of the stitch by the shuttle is illustrated in Figure 16 (*pl.* 53) and Figure 5 (*pl.* 54), in the former of which three different positions of the needle and the shuttle are shown. At *a* (*pl.* 53, *fig.* 16), the upper thread having been brought through the stuff by the needle, which has somewhat retrograded, the formation of the loop has begun, and the shuttle, carrying the lower thread, is about to pass horizontally (from left to right) with its pointed end through the loop thus formed. At *b* the shuttle appears as having passed three-fourths through, and at *c* as having finished its course, whereupon the ascent of the needle pulls the lower thread, by the proper adjustment of the tension, to the centre of the thickness of the material. This stitch corresponds with the intertwining of the moving thread (woof) and the stretched thread (warp) in gauge-weaving, the manner of holding the woof-thread in this case, however, being as enduring as the combination of the stuff itself. The second method of forming the lock-stitch consists in the loop of the upper thread being caught by a rotating hook, which expands the loop and passes it around a discoidal bobbin carrying the lower thread, as explained on p. 170. The shape and the action of the hook and bobbin are shown in Figures 10 and 11 (*pl.* 53). In Figure 10 the needle has the position in which the point of the hook catches the formed loop of the upper thread. This loop is enlarged by a further revolution of the hook, and in consequence of the peculiar shape of the latter is so guided that the loop is drawn over the bobbin. This process is nearly completed in the position shown in Figure 11. The loop of the upper thread leaves the hook after further rotation (*fig.* 10, to the left), and is drawn out in the production of the next stitch, by which both threads complete their interlacing. The advantage of this mode of forming the stitch is in the omission of the oscillating motion of the shuttle, thus doing away with the objectionable noise of the shuttle mechanism and making a larger number of stitches per minute.

Attachments.—Sewing-machines are provided with auxiliary devices called "attachments," which are designed for special work, such as hemming, tucking, cording, quilting, braiding, ruffling, etc., and by which the capacity of the machine is very much enlarged and its value greatly enhanced. Figure 9 (*pl.* 54) exhibits an attachment for gathering or forming ruffles in goods. Several varieties of work may be done with the ruffler, such as making scalloped edging, puffing, and shirring. Figure 10 is a quilter, the spaces between the seams being regulated by the guide, which is adjustable to any width within the limit of the apparatus. Figure 11 exhibits an adjustable plaiter or tucker, and Figure 12 a binder which shows the binding strip being lapped on the edge and stitched to the cloth. This attachment may be used for putting braid on the bottoms of dresses and for a variety of trimming devices.

Manufacturing Machines.—In sewing-machines modifications are frequently necessary in the external disposition of the parts when the articles to be sewed are to have a tubular or sack-like shape, such as sleeves of clothing, shoes, etc., the sewing-plate being in such cases replaced by a projecting hollow metal cylinder (*pl.* 55, *figs.* 1, 3) or a truncated pyramid (*figs.* 2, 4) for the support of the work. The machine exhibited in Figure 1 is used largely by manufacturers of gloves, pocketbooks, etc., and is adapted for all grades of shoe-work, but especially for vamping. The machine is furnished with a platform to make a work-plate on a level with the feed when a table is required for other work.

A great reduction in the prices of clothing has been caused by the use of manufacturing machines. This is especially marked in the production of shoes, whose output has been enormously increased since the invention of sewing and other machinery. While shoe-sewing machines do not strictly fall within the scope of the present section, we may be permitted to include a description of one example and also of a book-sewing machine, both of which are among the most important manufacturing machines of the present time, and which are typical of American ingenuity.

Shoe-manufacturing Machines.—The mechanical sewing of boots and shoes was for some time done on machines similar to the ordinary leather-sewing machines, but these did not satisfactorily reach the inside of the shoe to sew the "upper" to the "insole," although the soles could be sewed together by stitches put on the outside. The machine illustrated in Figure 4, in which a device at the end of the horn is made to act in conjunction with a hooked needle piercing the sole from the outside, seems successfully to fulfil the requirements. A large spool of thread coated with shoemaker's wax is attached to the rotating horn, through which the thread passes to a "whirl" at the tip of the horn. The whirl is a small ring through which there is an opening for the passage of the needle and having bevel teeth on the exterior, so that it can be rotated by a pinion which receives its motion by rods and bevel-gearing communicating with a cam movement in the rear of the upper part of the machine. During the descent of the needle through the centre of the

whirl, the latter makes a partial revolution, carrying the thread with it, the effect of which is to throw the thread into the barb of the needle. In preparing a shoe for the machine the upper is fitted to the form or "last" and to the insole, and the outer sole is then tacked on. The shoe is then placed on the horn and the stitching is begun, preferably near the shank. As the stitching proceeds the horn is rotated, and the shoe is moved thereon so as to bring it properly under the action of the needle. The needle, after penetrating the sole, has the waxed thread laid in its hook by means of the whirl, and in ascending draws a loop of the thread through the sole and the turned edge of the upper. A cast-off closes the hook and prevents the escape of the loop, while the shoe is moved for a new stitch. When the needle again descends it passes through the loop on its shank and draws a new loop up through the loop previously formed, thus enchaining one loop with another. The horn is kept warm by a lamp or by gas, which tempers the wax on the thread as it passes the horn.

Figure 5 exhibits a machine for webbing the linings and for staying the shoes. It is of the Willcox & Gibbs system, with double needle-bars, which are actuated by a single vibrating arm and fed from two spools, making two parallel rows of stitches. The tape is supplied from a roll placed on a bent rod or carrier above the machine. Figure 6 is a machine for overseaming the edges of blankets.

Book-sewing Machines are now largely employed to stitch together the sheets or "signatures" which make up the body of a book. These machines are remarkable not only for the great ingenuity of their construction, but also for the rapidity with which they operate and for the strength of their finished work. The Smyth machine is capable of sewing sixty signatures per minute, and inserts when required eight separate threads, any one of which may be cut or broken without impairing the holding of the others. In this machine each of the signatures is hung upon one of the horizontal arms of a four-arm reel, which presents the signatures in succession to the action of the clamps and the operation of the needles. The signature is secured by the clamps, the arm drops away, makes a quarter revolution, rises, and presents the next signature.

Embroidery-machine.—Closely allied to the sewing-machine is Heilmann's embroidery-machine (*pl.* 55, *fig.* 7). In this machine the needle, with a central eye, is guided in the manner illustrated in Figure 2 (*pl.* 53), but its great capacity is attained by the simultaneous movement of a large number of needles (from two hundred to five hundred, arranged in two horizontal rows), each of which repeats the flower or device on a piece of silk or other material from one governing design. The material to be embroidered is stretched smoothly in a vertical frame, which is movable in every direction in its own plane. Before each passage of the needles this frame receives a motion corresponding to the interval between two adjacent stitches, from a pantograph by means of a style called a "point" set further forward upon the design by the operator. Running on horizontal

rails in front of and behind this frame are broad carriages which carry a small nipper for each needle. All the nippers of each carriage can be simultaneously opened and closed by a simple mechanism operated by the attendant, so that all the needles can be liberated or grasped. From the above description the working of the machine can readily be understood. The needles, threaded through the central eye, are passed into the stuff by the advancing carriage on one side, while the nippers of the carriage on the opposite side seize the presented needles and pull them sufficiently through to tighten the threads. The frame is then shifted according to the requirements of the pattern, the needles are again passed through in another place, and, being seized by the nippers of the first carriage, are drawn tight; the frame is then shifted the interval of one stitch by means of the pantograph and the operation is repeated.

As will be seen, the capacity of this machine is based on the frequently mentioned principle of the duplication of the tool, the moving by natural forces, as in the case with the sewing-machine, being, however, impossible.

IV. AGRICULTURAL MACHINERY.

In no department of Mechanical Technics has there been more decided progress during the last half-century than in that which pertains to the production of machinery for agricultural purposes. Many of the implements in use at the beginning of the present century were scarcely in advance of those which had been employed from the earliest times. The object of this section is to mention some of the improvements that have been made, and to illustrate a few of the most important labor-saving machines of the present period. These will be considered in the order in which they are employed: machines (1) for tillage; (2) for planting and sowing; (3) for cultivating; (4) for harvesting; and (5) for thrashing and separating; to which will be appended (6) miscellaneous machines.

1. MACHINES FOR TILLAGE.

The Plough, though in use thousands of years ago, is still universally employed, and in many localities, as among the Malaysians and some African tribes, it yet retains its primitive simplicity. In the East it has always been a light and inartificial implement. It was known in Egypt and Syria before the Hebrews became tillers of the soil (Job i. 14).

The technical terms given to the parts of a plough are the *body*, that part to which all the rest is attached; the *sole*, the bottom, to the fore part of which is affixed the *share*, whose point expands into a *fin*, the hind part of the sole being called the *heel*; the *beam*, to which the team is attached and on the end of which is the *clevis*, a sort of rack or elongated staple, into which the draught-chain is hooked; the *coulter*, a cutting-iron fixed in the beam in a vertical position before the point of the share, for the purpose of cutting the furrow-slice from the fast-land; and the *mould-board*, the broad concave part which receives and lays over the furrow-slice cut off by the coulter and raised up by the share.

The Egyptian Plough (*pl.* 56, *fig.* 1), which doubtless was constructed simply of wood, consisted of a ploughshare, a double handle, and a pole or beam. The beam and the handle were fastened together, as seen in the illustration.

Syrian Plough.—Figure 4 shows the parts of a light plough used in Syria; it has a single handle and three different shares, for use in different soils. That metallic ploughshares were used in very ancient times is evident from the prophetic declaration, "They shall beat their swords into ploughshares" (Isa. ii. 4; Mic. iv. 3).

Grecian Ploughs.—The Greeks in the time of Hesiod (about 850 B. C.) used two kinds of ploughs. One was made of the limb of a tree with the branches so diverging as to form the different parts; the other was constructed of three sticks so fastened together as to form a plough similar to the preceding. Caylus's collection of Greek antiquities gives illustrations (*figs.* 2, 3) of wheel-ploughs used in the third century B. C.

Peruvian Plough.—With the advancement in agricultural science made

by the ancient Peruvians they "might be supposed to have had some knowledge of the plough, in such general use among the primitive nations of the Eastern continent; but they had neither the iron ploughshare of the Old World nor had they animals for draught, which, indeed, were nowhere found in the New. The instrument which they used was a strong sharp-pointed stake traversed by a horizontal piece, 10 or 12 inches from the point, on which the ploughman might set his foot and force it into the ground. Six or eight strong men were attached by ropes to the stake and dragged it forcibly along, pulling together and keeping time as they moved by chanting their national songs, in which they were accompanied by the women who followed in their train to break up the sods with their rakes. The mellow soil offered slight resistance, and the laborer, by long practice, acquired a dexterity which enabled him to turn up the ground to the requisite depth with astonishing facility. This substitute for the plough was but a clumsy contrivance, yet it is curious as the only specimen of the kind among the American aborigines, and was perhaps not much inferior to the wooden instrument introduced in its stead by the European conquerors" (Prescott).

The Modern Plough (*pl.* 56, *fig.* 6), with its mould-board to turn the broken-up soil, was invented in the Netherlands in the seventeenth century, and in the early part of the eighteenth century many ploughs were imported from Holland. The one most in use in America during the colonial period and well on into the present century had a wooden mould-board, sometimes covered with sheet iron, while the share was of wrought iron. This was followed by the cast-iron plough, which as first manufactured had a mould-board so rough as to necessitate scouring by protracted ploughing in a gravelly field before it could be used in adhesive soil. An important advance was made by using steel for the mould-board and by applying the chilling process to its entire surface, which by this means was made so smooth as to prevent the adhering of the soil. The important requisites of the modern plough now in general use are lightness of draught and steadiness of run, while it must produce a furrow of uniform depth and must properly pulverize the soil. The mould-board should be so constructed as to be adapted to the particular variety of soil in which it is to be used, and for this purpose admits of an almost endless variety of forms.

The "Jointer" (*fig.* 5) consists of a large common plough with a very small plough attached to the beam, in front of the large one. The small plough pares off the surface of the grass-sod, which is thrown into the previous furrow, and the large plough, following, turns up the under soil and throws its heavy furrow-slice over on the previous small furrow-slice and buries it deeply under.

The Reversible Plough (*fig.* 7) is so adjusted that the share and the mould-board may be readily changed from one side to the other. This plough is especially adapted to the ploughing of the sloping sides of hills, and its use on level land will avoid the making of a dead furrow. Among

other forms whose names indicate their uses are the subsoil-plough (*pl.* 56, *fig.* 8), the trench-plough, and the ditching-plough.

The Plough and Pulverizer (*fig.* 9) combines the operations of ploughing and pulverizing. The beam carries a small forward plough or mould-board, for removing a few inches of the top soil, which is pressed down or crushed by the pulverizing wheel into the bottom of the previous furrow, and a large or main plough, whose furrow-slice is not turned into the previous furrow, but on the interior of the pulverizing wheel of open iron framework, about 40 inches in diameter, which is close to the main plough and receives its turning soil. This soil, being carried around by the wheel, is disintegrated by its iron teeth and cross-bars and dropped out upon the turned sod in a pulverized condition. Thus at a single operation the soil is inverted, the weeds and grass are turned under, and the furrow-slice is finely divided without being trodden, as with the harrow. Arrangements are provided for regulating both the depth and the width of the furrow and for conveying the plough from one place to another. A seat is provided for the driver, as in the sulky-plough. A three-horse team is required to make thorough and satisfactory work in stiff soils.

The Sulky-plough (*fig.* 11), which may be easily worked by two or three horses, is supported by wheels, which bear the weight both of the plough and of the furrow-slice, thus greatly reducing the friction of the sole of the plough in the furrow.

The Riding-plough (*fig.* 10) dispenses with the pole and employs a separate guiding-lever and an automatic brake, which latter acts as soon as the plough leaves the ground and prevents its running on the team. By the manner in which the plough is hung its weight and the weight of the furrow are carried on the lubricated axles, thus preventing the great friction of the drag on the bottom of the furrow. The wheels, of which there are three, are set at correct positions so as to bring the weight on each alike. The two furrow-wheels are casters and can be locked square in line; they are constructed with automatic trips, so that in turning they will break from the direct line and turn a perfect square corner either to the right or to the left without requiring the plough to be lifted from the ground.

The Gang-plough (*fig.* 12) consists of from two to five or more ploughs arranged diagonally one behind another, so that the furrows are made to overlap one another. It is supported by wheels and is gauged for any required depth. Gang ploughs are drawn by teams or by steam-power (*fig.* 13)

Steam-plough.—It may be presumed that the day is not far distant when for ploughing tracts of considerable extent the use of steam will supersede that of animal power. The first plough worked successfully by steam was that patented by Mr. Heathcote, M. P., of England, in 1832. This was for breaking up and draining swampy land. The plough was drawn backward and forward by an endless chain, which received its power from a locomotive-engine placed on the headland. With some modifications this has been the plan adopted for ploughing by steam in England,

and until recently has been considered "the only available method." In the United States, however, the engine is attached directly to the gang of ploughs, as illustrated on Plate 56 (*fig.* 13). The entire plough-frame is a right-angled triangle having one of its sides parallel with the direction in which the engine travels, while the side to which the ploughs are attached is at such an angle that each plough is sufficiently in advance of its neighbor to allow all to turn their furrows. The ploughs are attached to the frame independently of one another in such a manner that each plough will cut a uniform depth regardless of the unevenness of the ground. In attaching the ploughs every possible condition required to draw them in the manner desired is most fully and simply met. They can be manipulated, in point of shallow and deep ploughing, with much greater facility than can be done with a team; for the line of draught is parallel with the bottom of the furrow, making it unnecessary to raise the hitch on the end of the beam for deep ploughing, as is the case when horses are used.

This frame has a transverse beam bolted underneath, and near the forward ends of the parallel and diagonal beam. This transverse or cross-beam is attached to the engine, about 18 inches below the main driving-axle, by two links; by this is overcome most of the tendency of the engine to lift the forward end of the plough-frame when the front wheels of the engine drop into a low place on the ground, and, again, being thus attached below the main axle, the draught of the ploughs counteracts to a great extent the disposition of the front wheels of the engine to rise off the ground when exerting great motive power, thus rendering these wheels more effectual as steering- or guide-wheels, and also overcoming the tendency to throw the entire weight of the engine on the drivers, which always causes trouble in soft grounds or in ascending grades. The forward ends of the plough-frame are suspended by links from extensions of the main axle on both sides of the engine; this, with the steering-wheel under the rear end of the plough-frame, carries the entire frame a uniform height from the ground. This steering-wheel under the rear end of the plough-frame is so connected with the front axle of the engine that both wheel and axle change their direction of travel at the same time, though in opposite directions; that is, when the front axle of the engine is turned to the right, the guide-wheel of the plough-frame is turned to the left, so as to cause the entire machine to move in a curved line, the arc of which always has the same proportion to the angles as the front axle of the engine and the guide-wheel of the plough-frame have to the driving- or main axle of the engine. This renders it practically impossible for the engine and the ploughs to move in any other course than the one desired. The ploughs are lifted out of the ground by means of a steam-cylinder operated by the engineer. It is claimed that this plough will in ten hours plough a field of fifteen acres, making a cut of 7 feet and ploughing at the depth of 8½ inches in hard dry ground, and that the expense for the work is not one-third as much as if performed by horses.

Implements for Pulverizing.—When a field has been ploughed, some

implement is generally employed to bring the soil to a condition fit for the reception of the seed. The common square-tooth harrow with teeth set at right angles to the frame was for a long time the only implement used for this purpose. It was an imperfect pulverizer, as the teeth were drawn square against the soil and were easily clogged. This has been generally superseded by several inventions whose object is to secure lighter draught, freedom from clogging, and a more perfect pulverization of the soil. Among these may be mentioned the Acme harrow (*pl.* 57, *fig.* 4) and the disc-harrow (*fig.* 5).

The Acme Harrow (*fig.* 4) is particularly adapted for working a ploughed-under sod. It has two rows of broad-cutting steel blades sloping backward and having a partial twist, like the mould-board of a plough. These "curved coulters" cut the land into slices and break up the surface, while the sod, which is undisturbed, is firmly pressed under and left in the very best condition and position.

The Disc-harrow (*fig.* 5) consists of twelve circular thin steel plates made slightly concave, to assist in pulverizing the soil. These discs, which are set slightly oblique to the line of draught in two gangs of six each, turn on a common axle and with a rolling motion cut through the soil, which by their turning is cast slightly sidewise and formed into small ridges about 6 inches wide. To this harrow there can be attached a seeder, thus combining two complete implements in one.

Rollers of a variety of pattern are also constructed for crushing clods and compacting the soil. As an example we give Provost's flexible field-roller (*fig.* 2), which is so constructed that the two large sections (drums) rise and fall in the middle, to conform to the unevenness of the earth, while in front of the middle there is attached a smaller drum, which presses down the seam of land left unrolled by the larger sections.

Figure 1 illustrates a roller for meadows or grain-fields or corn-land after planting. The two sections, each 3 feet in length, are supported on an arbor 6 feet 8 inches between the bearings, thus allowing for a space of 8 inches between the drums and enabling the operator to stride a row of growing corn, while each drum covers the space between two rows. The space between the drums is filled by two 4-inch spools, which can be taken off the arbor and placed one at each of its ends, thus closing the space in the centre and making a solid 6-foot roller for use on meadows or grain-land.

Figure 3 shows a combined clod-crusher, pulverizer, and corn-stalk cutter, which will cut two rows of corn-stalks at one time, while it will effectually pulverize large clods, leaving the ground so perforated that it will not readily bake in case of rain. When used merely as a clod-crusher, the position of the tongue is reversed.

2. MACHINES FOR PLANTING AND SOWING.

Seeding-implements: Cahoon's Broadcast Sower (*pl.* 57, *fig.* 6) consists of a small hopper, which is strapped to the shoulders of the operator, and

from which the seed is thrown by turning a crank, which causes a rapid rotary motion of the seed-distributer and throws the grain broadcast on each side at a distance which varies according to the weight and momentum of the different kinds of seed.

Figure 7 (*pl.* 57) shows a broadcast sower geared to and actuated by one of the hind wheels of an ordinary wagon, in the rear end of which it is placed. It is designed, by the use of gauge-plates and discs differently graduated, for sowing all kinds of grain and seeds as well as the ordinary commercial fertilizers. It can be so adjusted as to sow either a full cast or a half-cast, the former being for wheat from 36 to 40 feet wide. As the grain is not thrown at any point higher than the wagon-bed and is delivered to the ground with great force, it is not affected by the wind. It will sow from forty to eighty acres per day, depending on the variety of grain and the width of cast sown.

The Wheelbarrow Grass-seeder (*fig.* 12) is a very light machine, simple in construction and easy to operate. The hopper is carried so low that the wind does not affect the seed on its way to the ground. It will sow the exact quantity per acre that it is set to sow, and it makes no difference in the quantity whether the machine is run fast or slow.

Grain-drill.—The former slow and laborious method of broadcast sowing, or of dropping the seed by hand and covering it with a hoe, has generally been superseded by the use of machines, among which the grain-drill takes the most prominent place. There are several makes, which do not very essentially differ in their external appearance. For example we illustrate the improved Buckeye drill in Figure 8. The principal feature that distinguishes this machine is the method of gearing for the feed. The casing in which the gearing, called the "centre gear," is contained is pivoted on the steel axle at the centre and in part rests upon and is supported by the lifting-bar in the rear. The gearing consists substantially of three cog- or gear-wheels, the first of which is fastened to and is revolved by the steel axle; the second is attached to and revolves with the feed-shaft, which is underneath the hopper and extends the full length of the drill; while the third is a central wheel which transmits the power from the first to the second or from the axle to the feed-shaft (*fig.* 9).

Firmly fixed to the feed-shaft is a fluted feed-roll, which penetrates and entirely fills a cup-like attachment at the bottom of the grain-box or hopper. As the feed-shaft revolves it carries with it the fluted roll, which as it turns receives the grain admitted to the cup from the hopper, carries it around, and discharges it in an even, steady flow into the spout. The discharge of the grain is regulated by a "cut-off," which is operated by the lever or dial-finger seen at the right in the Figure. As the feed-shaft is moved laterally to the right or the left the fluted roll is moved in or out of the cup, by which means the discharge-opening is increased or diminished to suit the character or quantity of the seed. The feed will work with equal facility any of the various farm-seeds; in an improved form of the machine there is added a feed for fertilizers.

As both the spoke-wheels are drivers, it makes no difference in the sowing of the grain or seed whether they continue to move in conjunction or not. Either wheel may stop and the other one will keep the axle in motion, which, in turn, keeps the feed-shaft, and through it the grain- and seed-distributers, etc., in uniform and uninterrupted action. The great advantage of this arrangement is that by it all irregularity in sowing, or bunching of grain, is prevented.

There are employed eight or nine hoes, which are set, respectively, 7 and 8 inches apart. The feed-shaft is driven from the revolving axle by the centre gear, and in turn drives the grain-distributers, grass-seed sowers, etc. In front of the hopper is the seed-sower, which is so arranged that it may be shifted to the rear; it operates with equal facility in either position.

The lifting-bar, in the extreme rear of the machine, may be readily operated by the driver, who by means of it raises the hoes out of the ground, thereby disconnecting the centre-gear wheels, by which all the working parts of the drill are thrown out of gear. The lever for throwing the hoes out of or into line, or what is known as a zigzag position, is on the frame, at the right, within easy reach of the driver. The hoes, which are attached to the cast-iron spouts, have polished steel points; the rubber tubes from which the spouts are fed are wired and can be readily removed and replaced. The machine is provided with iron bars and springs so arranged and applied that any desired amount of pressure can be put on the hoes by means of the lever, or it can be used without any pressure. It is also supplied with gauges, to regulate the hoes so that they will drill of uniform depth whether in hard or in soft ground.

Under the grain-hopper and driven by the revolving axle is a land-surveyor, for accurately registering the number of acres sown. It registers only when the drill is seeding, as it is thrown out of gear by the lifting-bar simultaneously with all the other parts, and begins registering the instant the bars are returned to the ground and seeding is resumed.

Corn-planters.—The grain-drill may be used for planting corn in drills, but, as the rows must be farther apart than for other grain, generally not more than two of the tubes are employed. Planting-machines which will drop two rows at a time at right angles are used for planting corn in hills. Figure 1 (*pl.* 58) illustrates an implement of this kind. Each seed-plate contains fourteen seed-chambers, and different-sized plates are furnished, to plant from two to five kernels of average-size corn. The plates are rotated by a direct stroke against lugs on their outer edge by a sliding frame connected to the shake-bar. By the use of the combined hand- and foot-lever the runners can be properly controlled, giving a uniform depth to the seed. The machine has an attachment for planting corn in drill-rows, and also an attachment for planting pumpkin-seeds as frequently as may be desired. The wire seen at the right of the machine is termed a "check-rower." It has cast balls secured in the joints at equal distances apart and is stretched across the field. The machine is driven alongside

this wire, and is so connected with it that every time a ball is struck the dropper is opened and the seed is dropped and covered. When the end of the field is reached, the stakes to which the wire is attached are moved the width of the next two rows. The wire is a guide in driving and the balls insure exact cross-rows.

The Automatic Hand Corn-planter (*pl.* 57, *fig.* 10) drops the seed first into a receptacle and then into the ground. It plants with one hand as fast as a man can walk, and the depth of planting is regulated by raising or lowering an adjustable slide.

The Keystone Corn-planter (*pl.* 58, *fig.* 2) may be so adjusted as to regulate the depth of furrow, to cover thick or thin, or to plant any number of grains any required distance apart. It will plant from ten to twelve acres of corn per day, dropping the kernels in hills or in drills, and will at the same time, if needed, sow any kind of pulverized fertilizer.

3. MACHINES FOR CULTIVATING.

Cultivators.—"Tickle the earth with a hoe and it will smile with a harvest" is a maxim which has been practically applied from the earliest times by the use of some implement suited for the purpose. The importance of thorough cultivation to keep down the weeds and to loosen and mellow the soil can hardly be overestimated. Formerly the hoe and the harrow were the only tools employed, and, as the hills were not in exact cross-rows, much hoeing was required. Most farmers now so plant that the hills will admit of horse-cultivation both ways, and for this purpose a variety of implements has been devised, of which the following are typical examples. Figure 6 (*pl.* 58), styled a "tongueless walking-cultivator," has four shovels, steel or wood beams, and the pivoted hitch and wheel device, which allows one horse to draw ahead of another without interfering with the working of the beams and shovels. Figure 5 employs six shovels for purposes of cultivating, but by the addition of a seventh shovel-attachment it can be used to advantage for ploughing in summer fallow. Figure 4 shows a combined harrow and cultivator. Figure 3 is a disc corn-cultivator which has between the gangs a shield for the protection of small corn.

4. MACHINES FOR HARVESTING.

The scythe, the sickle (*pl.* 59, *fig.* 4), and the cradle (*fig.* 3), implements everywhere in use a half-century ago, are no longer employed in extensive farm operations. The mowing-machine has taken the place of the scythe, and the reaping-machine has been substituted for the sickle and the cradle.

The first reaping-machine of which there is record was described by Pliny about A. D. 60 (*fig.* 1). It was in the form of a cart which had in front a comb-like bar (*fig.* 2) that stripped off the heads of wheat and deposited them in a box. It was propelled by an ox walking behind the machine. Pitt in 1786 constructed in England a machine in which a

cylinder armed with combs plucked off the ears and discharged them into a box. This was the forerunner of the present form of machines. In 1822, Henry Ogle of Alnwick, England, constructed a machine in which a reciprocating motion was given to the cutters. No great efficiency, however, was attained until the invention of the American reaper by Hussey in 1833 (*pl.* 59, *fig.* 5), and by McCormick in 1834. For the next twenty years improvements were continuous, but it was not until about 1850 that the usefulness of the reaper was universally acknowledged. Combined machines —that is, machines which could be used alternately for cutting both grass and grain—were widely used for many years. It has, however, been found that a machine designed for both kinds of work does not perform either so well as one which is made especially for one kind, and therefore it is now generally considered advisable to have one machine for mowing and another for reaping.

Mowing-machine.—As it would be impossible to do justice to all by attempting to describe the different inventions which have been applied to the modern mower or to speak of its various forms, we shall give an illustration and description of the construction and operation of but one machine (*pl.* 58, *fig.* 7), which may be considered as a specific type combining many desirable modifications. The most important parts are the knife, finger-bar, and guards or fingers, which are practically the same in all machines. Figures 8, 9 exhibit sections of these parts on a larger scale than is seen in the complete cutting-apparatus. The knife is driven by the pitman, which is operated by a crank-wheel actuated by suitable cog-gearing (*fig.* 8), to which motion is imparted by the forward movement of the driver-wheels. The serrated blade, which passes through a narrow slit in each of the fingers on the finger-bar (*fig.* 10), is made to vibrate rapidly to and fro by the cog-work of the machine, and, operating on the standing grass like a number of powerful shears, severs every plant in its course. The pitman is attached to the knife by a ball-and-socket joint, which admits of flexibility of movement in every direction. For adjusting the cut the points of the guards can be raised or lowered by a tilting-lever convenient to the hand of the operator. To transfer the machine from the field the cutting-bar is raised and fastened in a vertical position.

Hay-tedder.—After the grass has been cut it should be dried as evenly and as rapidly as possible. The mowing-machine leaves it a compact mass of parallel stems which need to be shaken up and to be thrown one across another in every direction that they may be exposed to the full influence of the sun and the air. This is accomplished by the tedder (*fig.* 11), which has the capacity and power to ted the heaviest hay or grass and will shake out hay in windrows even if thoroughly soaked with water from rain. The forks are operated by a crank-shaft in bearings on the frame of the machine and can be lowered or raised by a tilting-lever, which is easily reached by the driver; the shaft receives its motion from cog-gearings, which are on the runner-wheels and which engage a small cog-wheel on each end of the crank-shaft.

Horse-rakes.—When the hay is sufficiently dried, it should be immediately housed or stacked. The old method was to gather it in windrows with a hand-rake, but this was a slow and laborious process, requiring too much time, which to the farmer is money, especially when the day is far spent or when his spread-out hay is threatened by an approaching shower.

The Original Horse-rake (*pl.* 58, *fig.* 12) had about fifteen teeth so set in a piece of strong scantling that they would run flat on the ground under the hay. It was held by the handles, by which it was kept steady, and by which it was also tipped when the load was to be emptied. The draught-ropes were attached to short teeth at the end of the rake, as seen in the illustration.

The Revolving Horse-rake (*fig.* 13), which was next generally adopted, could be unloaded without lifting the rake or stopping the horse, as a slight motion of the handle induced at each windrow a semi-revolution, by which the load was discharged and the opposite teeth were brought into work.

The Self-operating Hay-rake (*fig.* 14) has a solid revolving iron axle, which by ratchets in the hubs of the wheels furnishes the power for discharging the load and is actuated by the onward movement of the horse. The framework is united securely to the axle and the steel teeth are fastened into the rake-head, which for discharging the load is thrown into gear by means of a divided lever that remains stationary when the load is dumped. The rake is held by a centre latch, which when disengaged allows the teeth readily to fall back.

The side-delivery rake, recently introduced, will gather and turn into a windrow two mowing-machine swaths, and in this way answers the purpose of both a rake and a tedder. This may be followed by the hay-loader, an ingenious device which gathers up and rolls the hay upon a wagon, to whose rear it is attached and by whose forward movement it is actuated.

Hay-forks and Hay-carriers.—The former laborious method of unloading hay and grain has been superseded by the use of the horse-fork and carrier; the operation is performed by horse-power in one-sixth the time required by hand. Among the various forms in use the harpoon-fork (*figs.* 15, 16) is the simplest. It consists mainly of a single iron bar having at the lower end a point, just above which are two concealed spurs. This bar is plunged into the hay, and as the horse starts to draw it up by the rope which is attached to its upper end the spurs are thrown out and bear up from 100 to 200 pounds of the hay into which the bar has been thrust. This fork is fitted only for hay which has long fibre and will hang well together. For short or light hay or for barley-straw the double or grappling-fork (*fig.* 17) must be employed. This has two sets of arms pivoted together at the top, each set composed of three long tapering spring-steel tines; the arms when spread stand nearly 5 feet apart and the tines enter the material about 2 feet; it closes and holds the load by

its own weight and can be worked successfully on all kinds of hay, straw, etc. It is opened easily and works rapidly, taking off with each forkful about 400 pounds, averaging half a ton a minute. The illustration shows the method of moving each forkful by means of the hay-conveyer, with which is connected a car that runs on two rails of wood 5 inches apart hung close to the peak of the barn. For stacking hay or grain there is used another form of car, with the parts so modified in form and adjustment as to adapt them to work satisfactorily on a rope stretched between two pole-tripods set far enough apart to give room for the stack and the wagon.

Reaper.—In the use of the mower the cutter-blade passes through the grass, which immediately falls over the finger-bar and lies on the ground in a swath; but in the reaper a platform is required back of the finger-bar, to collect the falling grain. In one of the earliest devices, when enough grain had accumulated for a bundle, it was swept off by a hand-rake and was subsequently bound (*pl.* 59, *fig.* 6). In the self-raker (*fig.* 7), which is of more recent construction, the grain is cast off in neat gavels by the machine. In the self-binder (*fig.* 8) the sheaves, by an automatic arrangement, are bound and dropped from the machine. For bands self-binders originally employed wire, which was reeled from a large spool as it was passed round the bundle, and was then twisted together and cut off by automatic shears. Cord is now in general use.

No agricultural machine requires more care and skill in its make than the harvester and binder. It must cut crops varying from wheat 1 foot high to rye whose barbed heads wave 6 feet from the ground; it must cut tangled and lodged grain, arrange it in good order, and convey it to the binder-deck, where it must be seized by the sensitive packers and formed into sheaves, which must be securely bound and discharged in exact time. This must be done on side-hills and over rough and uneven ground. The machine must be strong, and yet sufficiently light for an ordinary team. It must tilt by the touch of a finger, and its levers must be so adjusted as to require no effort on the part of the driver. It must reap with equal facility clover and flax, oats and barley, wheat and rye.

In California are found not only the largest wheat-fields in the world, but also the most elaborate and efficient machines for harvesting (*fig.* 9). On the borders of the San Fernando ranch there is a single wheat-field containing one hundred and forty-four square miles, to plough which there must be turned a furrow twelve miles long. In time of harvest the San Joaquin Valley presents a sea of grain as wide as the visible horizon and as long as a day's journey by rail. If to these there be added the Valley of the Sacramento and a multitude of valleys of like productiveness, though of lesser area, which help to make up the three and a half million acres of California's grain-fields, we shall have some idea of the amount of labor required to secure the crops. To plough these extended tracts by the old methods would be a tedious operation, but to harvest the grain in the proper time by the use only of ordinary machines would be an impossible task.

5. MACHINES FOR THRASHING AND SEPARATING.

The powers in common use for driving thrashing-machines are steam-engines, lever-powers, and horse-tread powers, of which the latter have many advantages over all others, as they may be easily conveyed from one place to another, may be placed on the barn floor where the thrashing is to be performed, and require little preparation and few men to run them. Figure 1 (*pl.* 60) shows a two-horse tread-power, the upper portion being the enclosure in which the horses work, while the lower part consists of a travelling platform, operating on anti-friction rollers moving over cylindrical drums, one of which is at rest while the other revolves. On one side of the revolving drum, at the head of the machine, is a large gear-wheel, which engages with the cogs on the band-wheel shaft, which latter is caused to revolve by the platform passing over its periphery.

Figure 2 illustrates a combined thrasher and cleaner, by which the grain is completely separated from the straw and delivered ready cleaned into bags. The machine is of simple construction, light-running, and effective. The cylinder is made either of wood or of iron; in the latter form strong wrought-iron bars running lengthwise contain steel teeth, which are fastened to the bars with screw-nuts. The concave, which is in two parts, is of iron lined with wood and furnished with steel teeth, and is made adjustable by set-screws. The belt that drives the cylinder-shaft operates the various parts of the machine, thus avoiding a complication of belts or gear. Other attachments, not shown in the Figure, are a "tailings"-elevator and a straw-stacker.

Figure 9 illustrates a straw-stacker and the form of stack which it constructs. This stacker can be attached to any separator by bolting a wooden pulley on the outside of some convenient pulley on the separator and running from this pulley a belt back to the stacker. By an automatic device the carrier is swung round, and in passing moves so slowly that in a half revolution it makes a good layer of straw all over the stack. When not in use, it can be folded back on the wagon, upon which it is fixed.

The Victor Clover-huller (*fig.* 3) combines in one machine an apparatus for hulling, separating, and winnowing the seed and placing it in a bag. The upper huller, into which the clover is first fed, consists of an under-shot open iron-bar cylinder (*fig.* 4), which is provided with steel fluted rubbers and so revolves in a concave, also provided with fluted rubbers, that the edges of the revolving rubbers in the cylinder pass between the edges of the rubbers in the concave, thereby breaking up the pods and in part removing the seeds. From this first cylinder the clover passes into the separator, which takes the bulk of the coarser material from the unhulled pods and carries or rakes it to the rear, where it is removed from the machine by a carrier. The clover-pods and seeds that fall between the raker-bars of the separator are pushed forward into the lower huller. The seed, unhulled pods, chaff, and finer stems discharged from the lower huller pass to a zinc stem-riddle, through whose holes the seed, pods, and finer stems drop, and are returned by the conveyer to the upper cylinder, to

be again subjected to the action of the two cylinders, while the coarser stems are blown out with the chaff. The two woven-wire screens, one having five and the other eleven meshes to the inch, are fastened in a frame, which is driven by two pitmans (one on each side of the cleaner), connecting with a crank-shaft having on either side of the cleaner two cranks, to one of which, on each side, are connected the pitmans operating the stem-riddle. Through a lower screen or sieve, of perforated zinc, the seed passes, and is separated from the coarser material not blown out by the fan. The seed from the sieve goes into a small elevator and is carried up to the seed-recleaner, which, fastened to the side of the machine, thoroughly cleans and discharges the seed into bags.

Fan-mills and Corn-shellers.—Since the general adoption of thrashing-machines combining separators the hand fanning-mill (*pl.* 60, *fig.* 6) is much less employed than formerly. It has of late years been so improved that it will clean grain of foul seeds and separate the larger from the smaller berries of the same kind of grain, thus enabling the farmer to select the largest and best for sowing. The separation of the varieties of seed is effected by a series of differently-meshed screens, through which the grain falls, while at the same time the chaff is blown out by a rotary fan. Figure 5 exhibits a four-hole self-feeding power corn-sheller.

6. MISCELLANEOUS AGRICULTURAL MACHINES.

Ensilage-cutter.—Ensilage is fodder preserved in a *silo* or pit or in an air-tight structure above ground. The process is analogous to that by which fruits, meats, vegetables, etc., are preserved in cans. In the United States in 1880 there were only six silos and in England only four, while in the former country they had increased in 1885 to nearly two thousand and in the latter to eleven hundred and eighty-three. These have demonstrated that it is practicable to store corn, millet, clover, etc., in a moist but sound and sweet condition for use at any subsequent time. Indian corn, the principal plant used for ensilage, requires cutting into pieces from ½ an inch to 1 inch in length. Figure 7 represents an ensilage-cutter with four knives. The capacity of the machine is increased by a change in the movement of the feed-rollers and by enlarging the throat of the cutter. By special mechanism the cutter operates a carrier or elevator for the delivery of the ensilage to the above-ground silo.

The Potato-digger, illustrated in Figure 11, consists of two large drive-wheels with adjustable grabs for holding the power in soft ground; these wheels operate an endless chain with elevators attached and combined with a grate-bar, which has a continuous jarring motion. The point or shear is a broad, highly tempered, polished steel plate. On each side are revolving knives, which cut the vines and weeds and prevent clogging. Directly over the elevator is the driver's seat, with operating-lever in front, for lifting the shear out of the ground at the ends of the furrows or for raising it over obstructions. The basket, which holds about a bushel, can be used when the soil is free from lumps and weeds, and is dumped by the

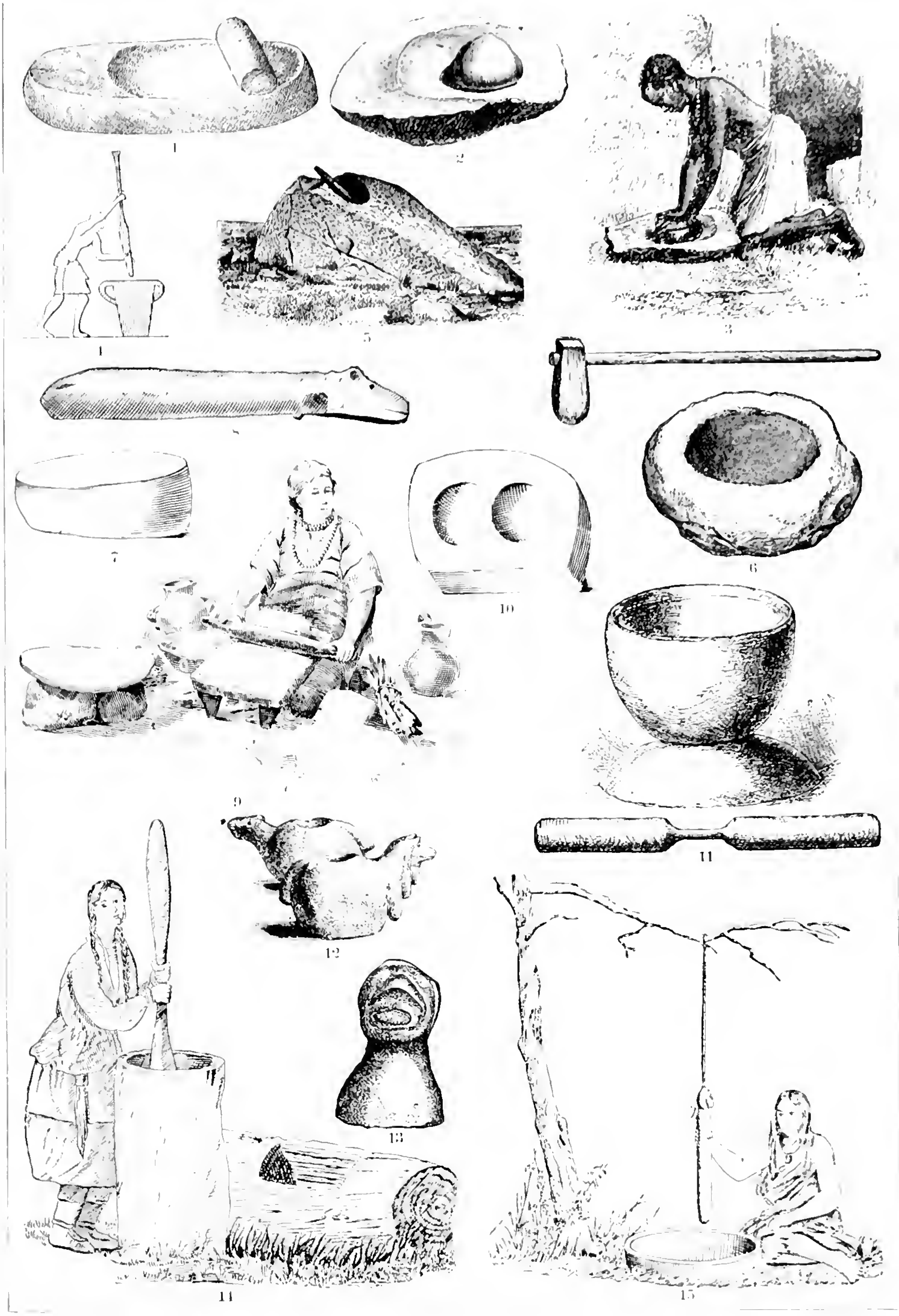
driver without stopping; it leaves the potatoes in piles; or by using the rear grate they can be left directly behind the machine or at one side in rows.

Baling-press.—When hay is to be shipped long distances, it must be baled that it may be handled with ease and transported with safety. For this purpose there is employed powerful compressing machinery, of which Figure 10 (*pl.* 60) is an example. This machine is double acting—that is, a charge of hay is fed into it at each turn of the horse, which travels back and forth on less than half a circle. As the bales are made and tied they are discharged through the open bale-chamber without stopping the machine. Its compound power is effected by three links, which connect the power-head to the pitman. The knuckle-arms are each of one piece, and both the arms and the power-head have bearing surfaces on separate shafts and extend from the lower to the upper frame. The extended pitman gives the plunger a long in-stroke and a fast travel at the start, while the material in front of the power-head is in a loose condition. As the hay becomes compact the power increases proportionally until the pitman passes the centre. By the compound lever-power of this press the team has a leverage of 132 : 1; that is, if a horse pulls 1000 pounds, a pressure of 132,000 pounds is placed on the material when the pitman is drawn over the centre, thereby insuring bales of great density.

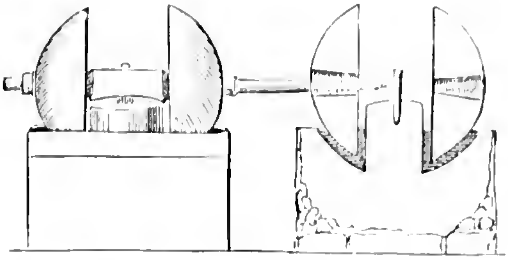
The Manure-spreader (*fig.* 8), a cart provided with a tongue, to connect it with the forward wheels of any farm-wagon, has a movable bottom similar to the travelling-bed of the tread-power described on page 188. As the cart advances this bottom moves slowly and carries the manure toward the rear, where it is caught by the teeth of a swiftly-revolving cylinder, torn into fragments, and scattered on the ground. The operating mechanism is actuated by the cart-wheels by gearing. The machine is used for spreading broadcast every kind of manure, lime, ashes, marl, etc., in any desired quantity. Any concentrated fertilizer may be easily mixed with the manure by placing it on the top of the load, and the quantity of fertilizer required for each acre may be accurately regulated.

Conclusion.—The agricultural implements herein depicted and described are exclusively of American manufacture. The superiority of these machines is evidenced by the fact that they are fast being introduced into nearly all the countries of the world, the total value of the exportations from 1864 to 1884, inclusive, being $42,534,450.

"It may be well to premise that we do not import agricultural implements, for two reasons: (1) European implements are not wanted by our farmers, and would not generally be used could they be obtained at half-price. As a rule, they are too cumbrous and clumsy, requiring too much power and accomplishing their work too slowly. (2) American machines are better adapted to specific uses, without unnecessary strength and weight, as our timber is tougher and stronger in proportion to weight, their superiority giving them a market in all parts of the world" (*Special Report No. 56*, U. S. Department of Agriculture).



PRIMITIVE IMPLEMENTS:—1. Prehistoric slab-mill (Stone Age). 2. African corn-mill. 3. African woman grinding corn. 4. Egyptian wooden mortar. 5. Glacial boulder with pot hole (Trenton, N. J.). 6. "Knockin' Stane" and mallet (from Shetland). 7. North-American Indian corn cracker. 8. Indian pestle with totemic symbol head (from Massachusetts). 9. Mexican metate. 10. Indian double-chambered implement (from New York). 11. Ainu millet mill and pestle. 12. Peruvian stone mortars (from Huarmachaco). 13. Figured pestle (from Porto Rico). 14. Indian hominy block (wooden mortar and pestle). 15. Pennacook Indian woman pounding maize with a suspended pestle.



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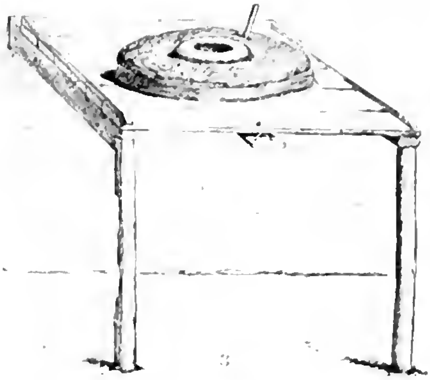

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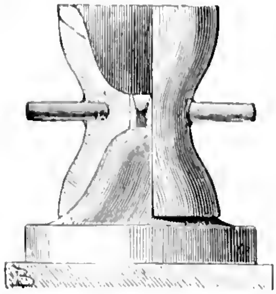

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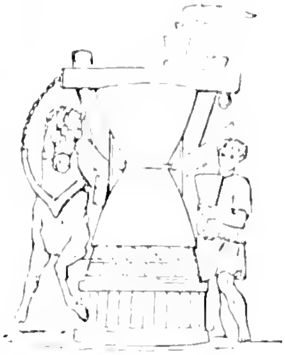

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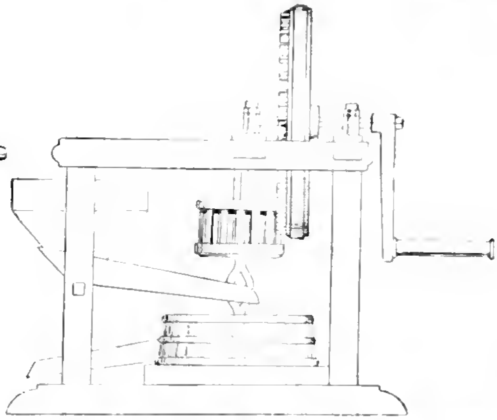

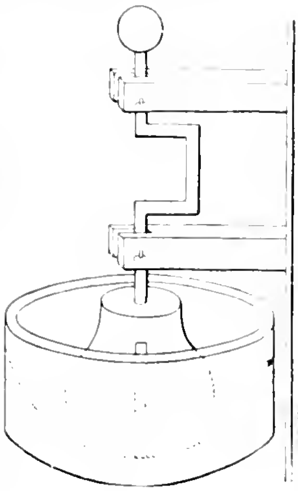

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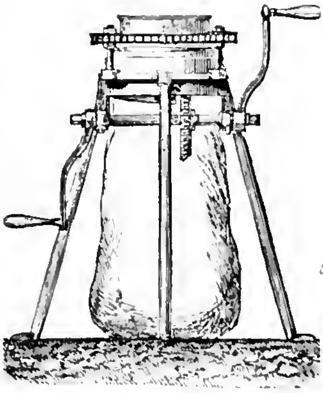

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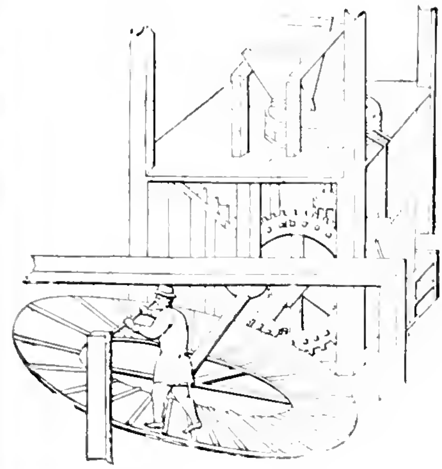

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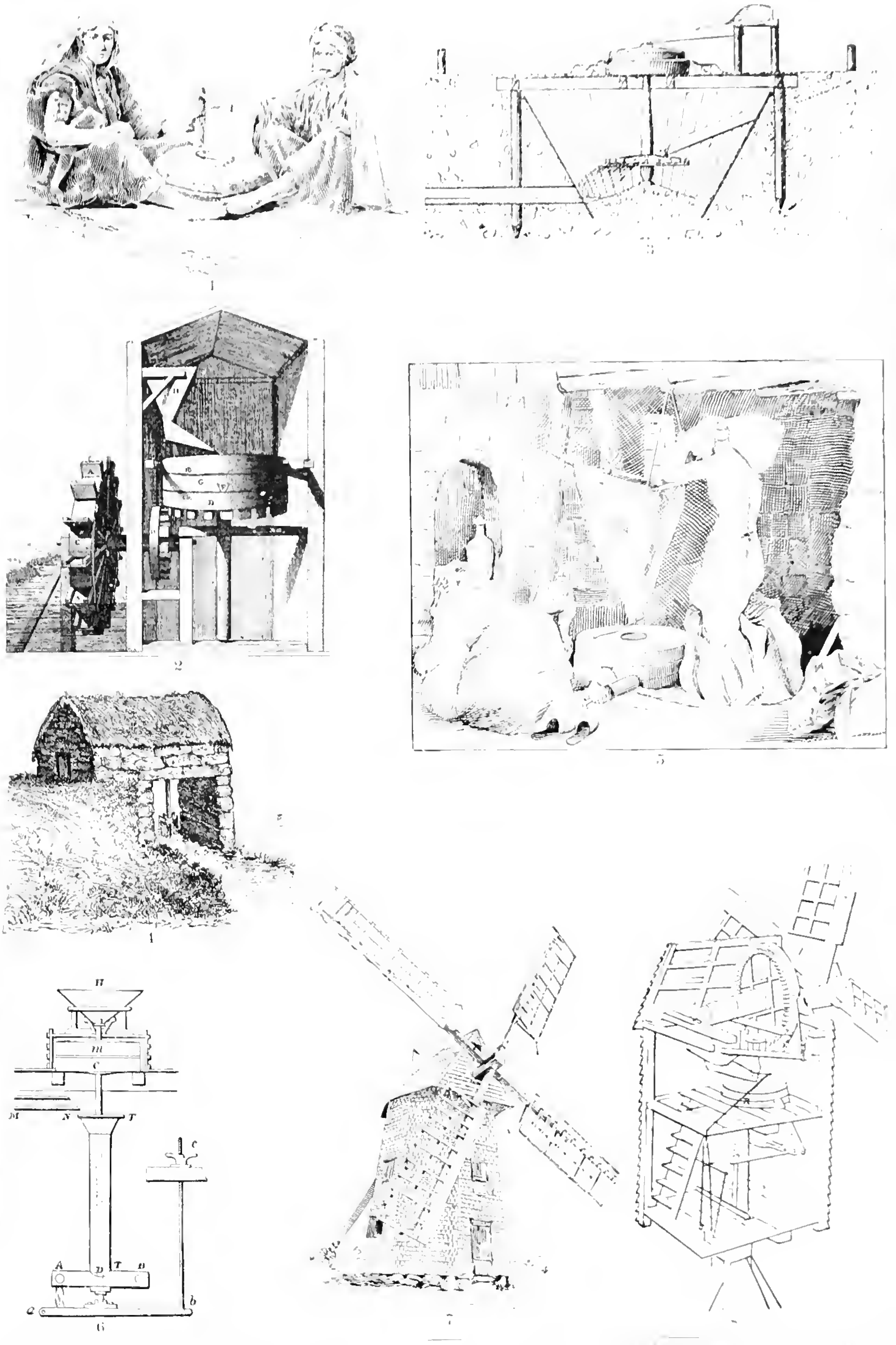
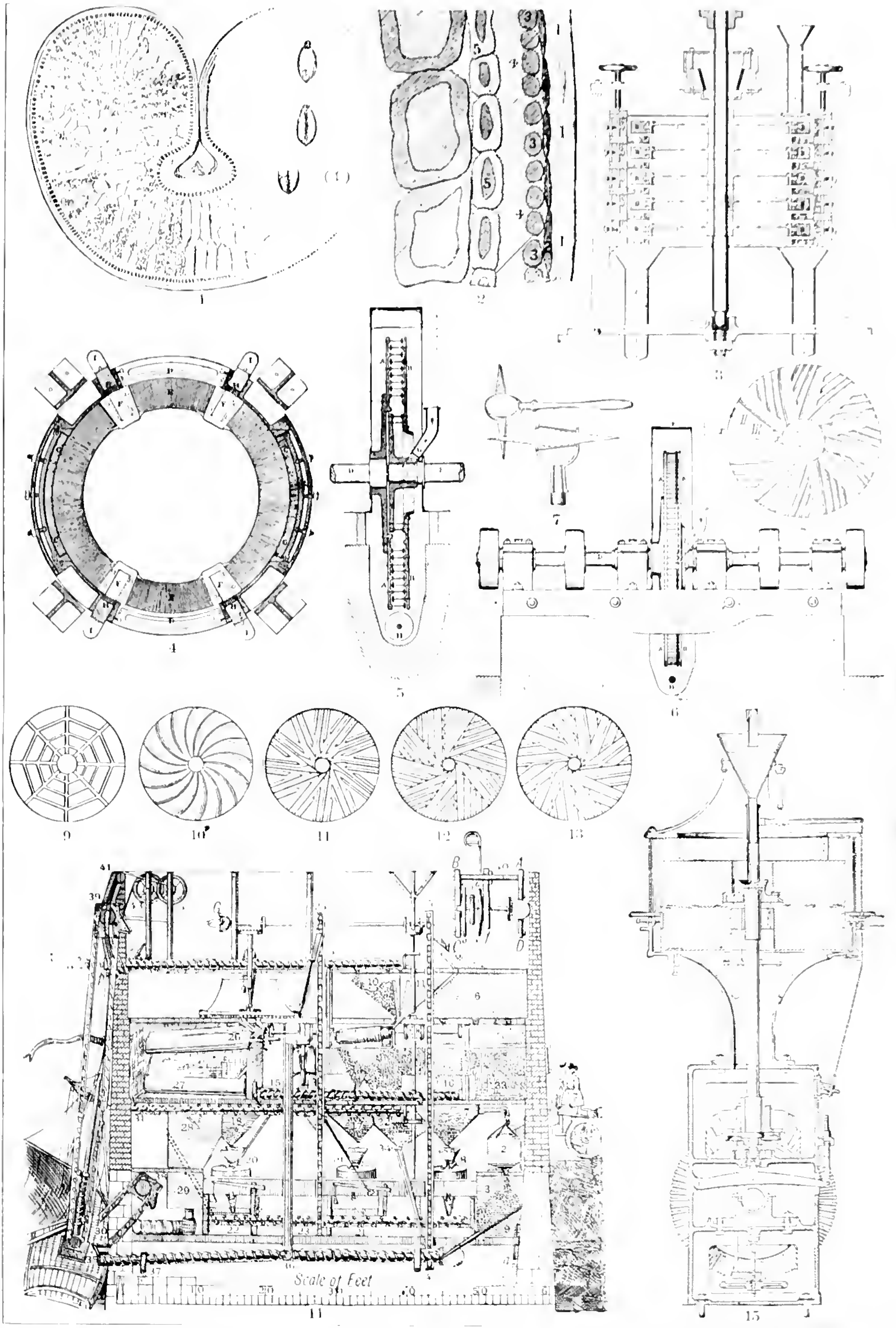
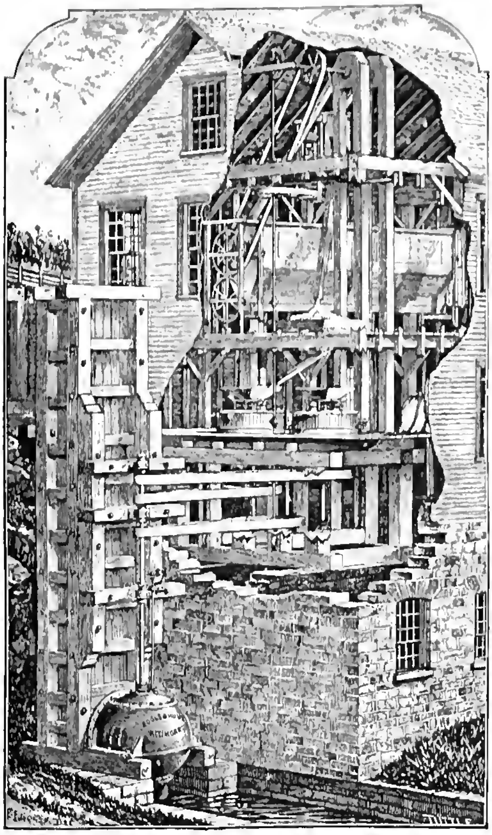
1. Ancient chaser (*trapetum*) for grinding olives. 2. Cross-section, 3. Perspective, of a Scottish [illegible] (from North Yell). 4. Roman corn mill (*catillus*) from Pompeii. 5. Mola asinaria or machinaria. 6. [illegible] mill. 7. [illegible] mill. 8. Simple hand mill. 9. Tread-mill. 10. Eastern millstones (reproduced from a photograph [illegible] Selah Merrill).



1. Eastern mill (from a photograph furnished by Selah Merrill). 2. Roman water mill. [illegible] man water mill. 4. "Norse" water-mill of Shetland. 5. Turkish mill. 6. Barker's mill. 7. Old wind-mill at Nantucket. 8. Post wind-mill.



1. Wheat grain (natural size and magnified). 2. Section of covering of a wheat grain [illegible]. 3. B[illegible]holz's hulling or decorticating-machine. 4. Plan of casing and blade (enlarged) of Bach[illegible] mill. 5. Vertical section, 6. Side elevation, of Carr's disintegrating mill. 7. Mill [illegible]. 8–13. Dr[illegible]. 14. [illegible] mill (vertical section). 15. Fairbairn's corn mill.



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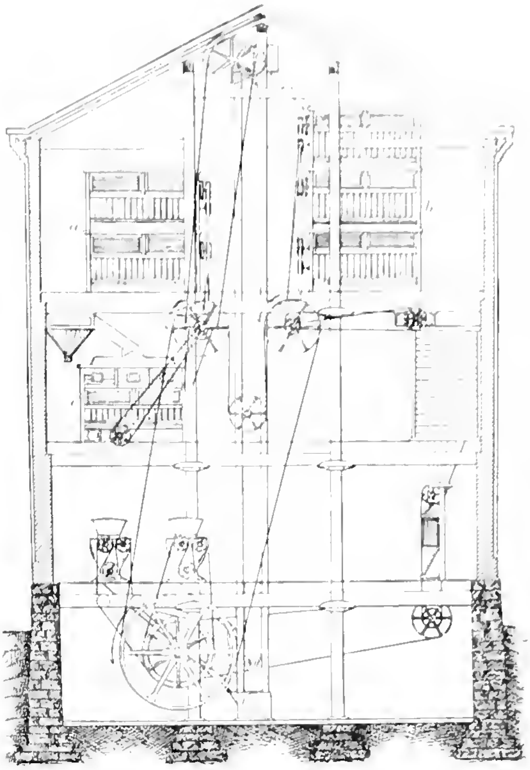

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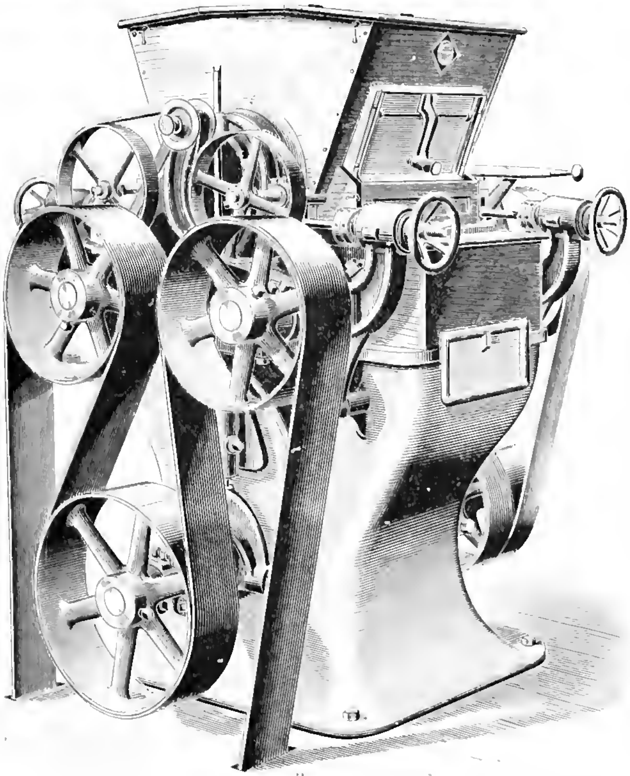

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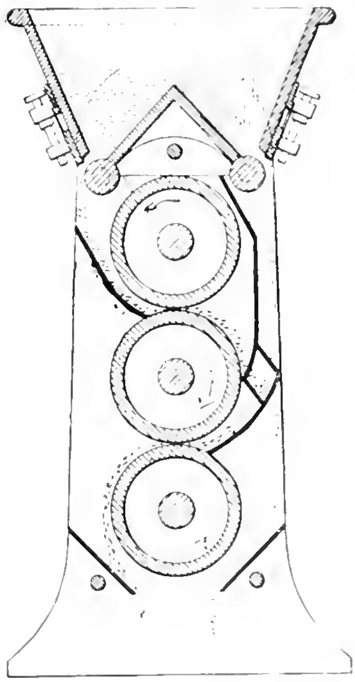

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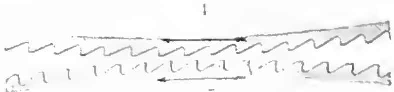

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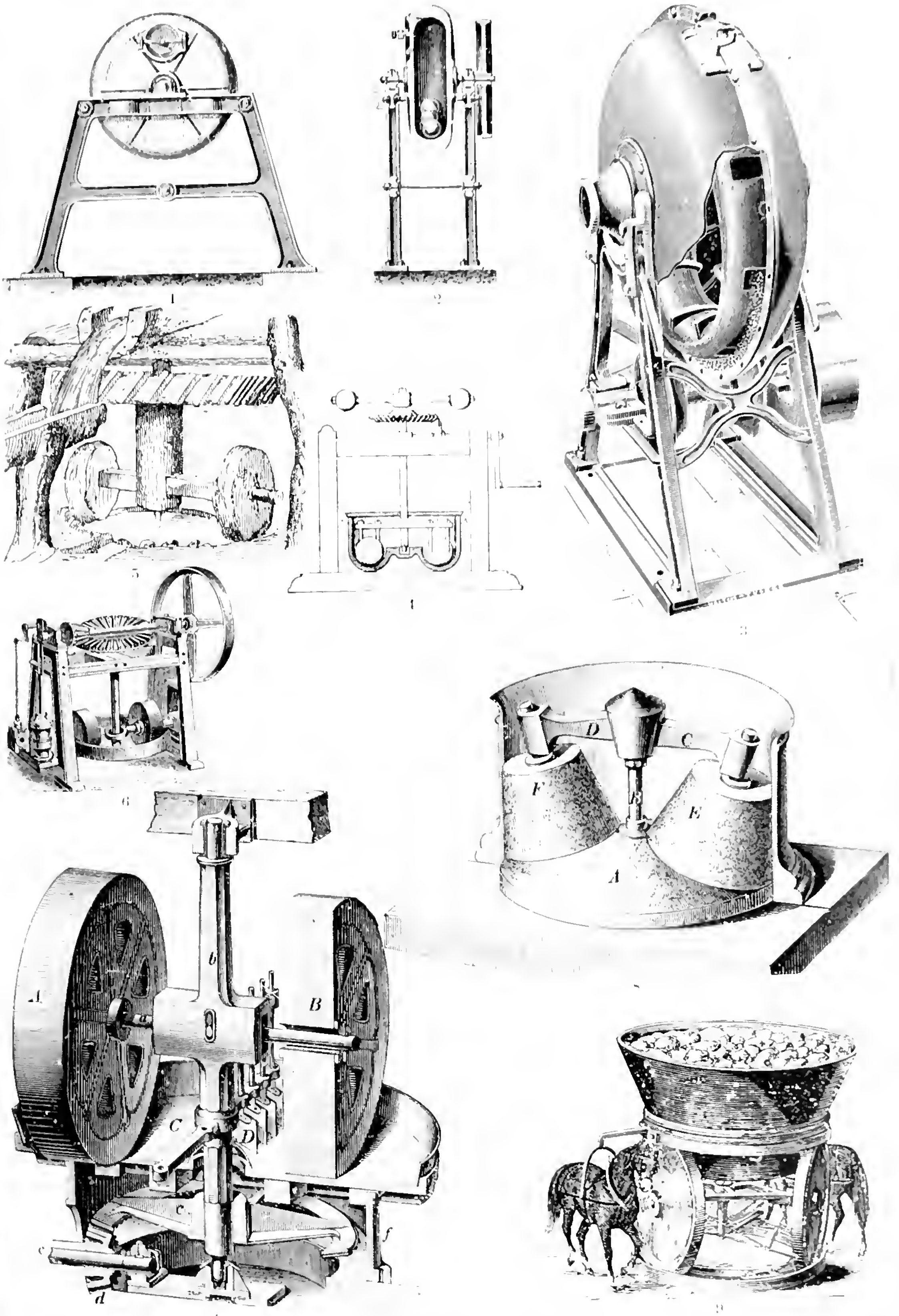
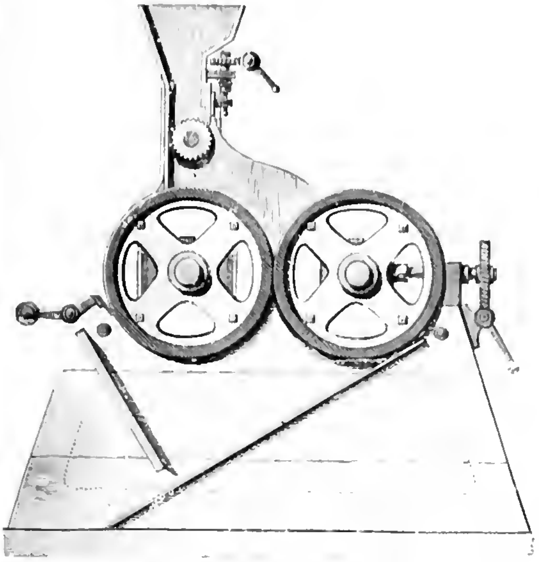
1. Modern millstone mill, driven by a turbine (Robert Poole & Son Co., Baltimore, Md.). 2. Modern 200-barrel roller-mill (vertical section). 3. Gray's "Noiseless" four roll roller-mill (Edward P. Allis & Co., Milwaukee, Wis.). 4. Vertical section, 5. Periphery of rolls, of a three-high roller-mill.



1. Elevation, 2. Cross-section, of a ball mill. 3. Silent-grinding mill (A. M. Hill, New Haven, Conn.). 4. In[illegible] mill. 5. Edge-stone or "Chilian" mill. 6. Modern edge-stone mill with steam engine attached. 7. Edge-stone mill. 8. "Cycloidal" mill. 9. Hitchcock's quartz-crusher.



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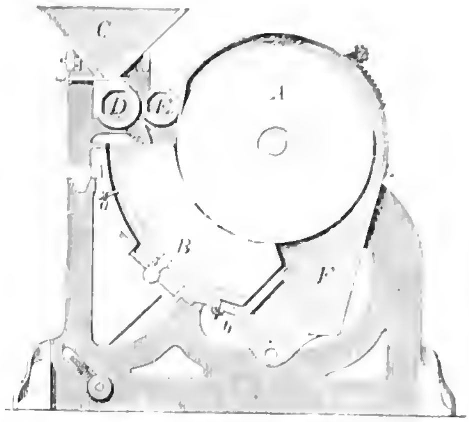

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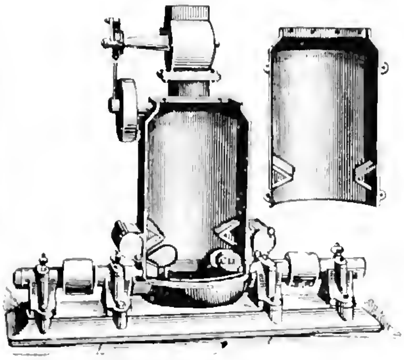

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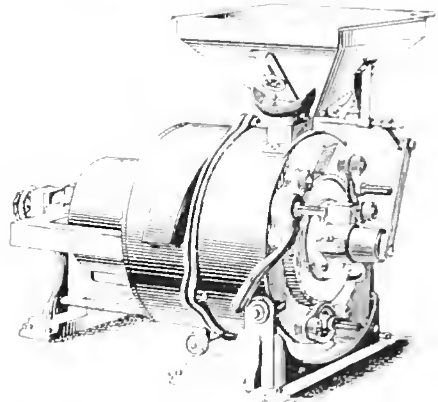

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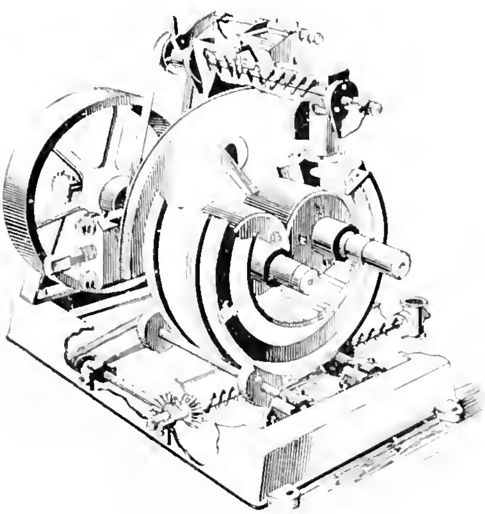

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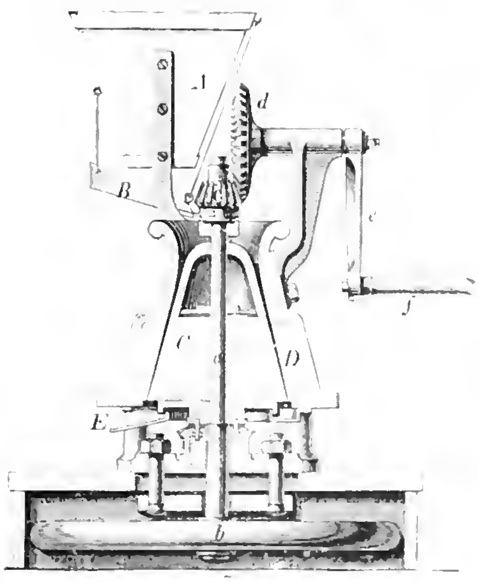

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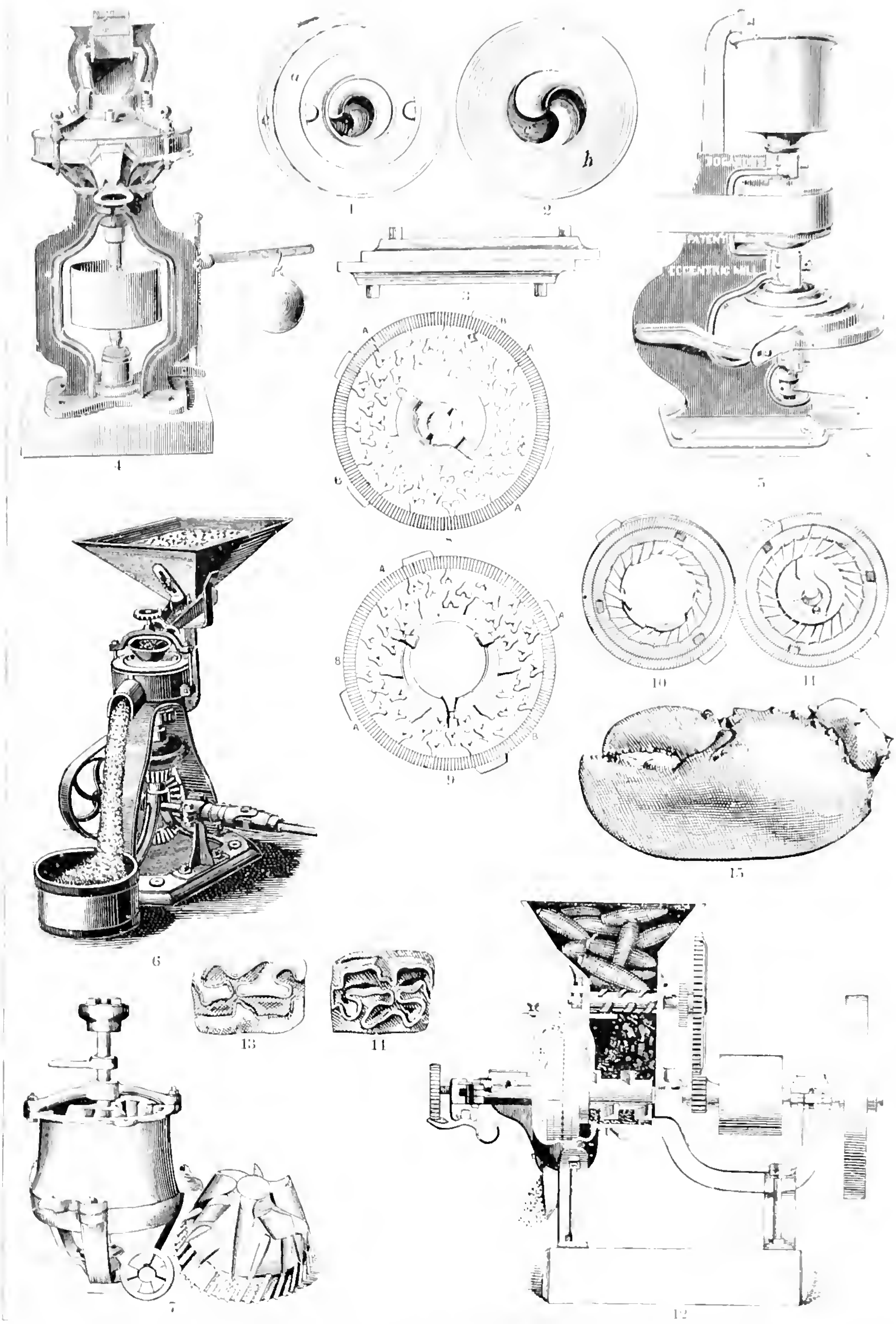
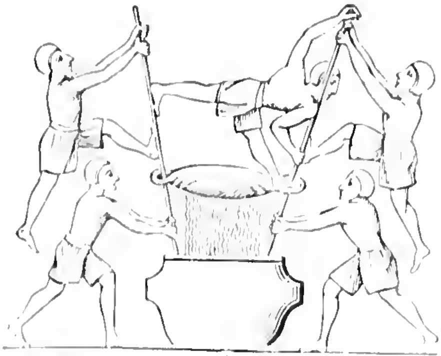
1. Hollow cylinder malt crushing mill (lengthwise vertical sec[illegible] 2. A[illegible] paints. 3. Concave-bed roller mill (vertical section). 4. "Cyclone" pulveri[illegible] 5. [illegible]
6. Gates's roller pulverizer (partly in section). 7. Conical mill with vertical axis (verti[illegible]



1. Face of grooved plate. 2. Edge view. 3. Plan of super[illegible] plates, of the Bo[illegible] [illegible]; 4. "[illegible]tric" mill for dry substances. 5. "Eccentric" mill for wet substances. J. S. & G. F. S[illegible], B[illegible], N. Y. [illegible] farm mill. 7. Corn and cob crusher. 8-11. Grinding plates. 12. Elevation partly in section, of the "S[illegible]" mill. 13. Cross section. 14. Crown, of horse teeth. 15. Bolster claw.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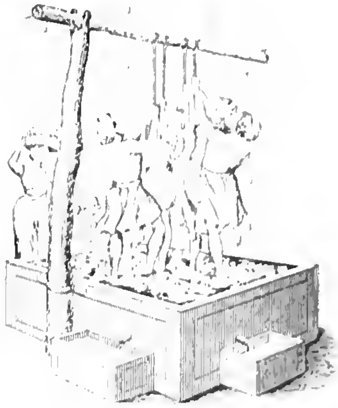

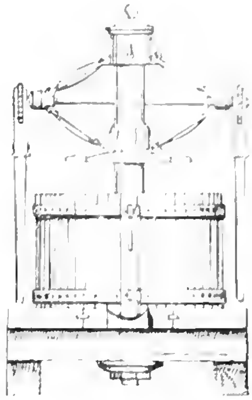
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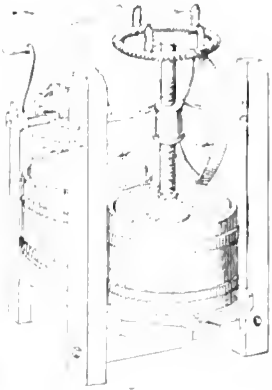
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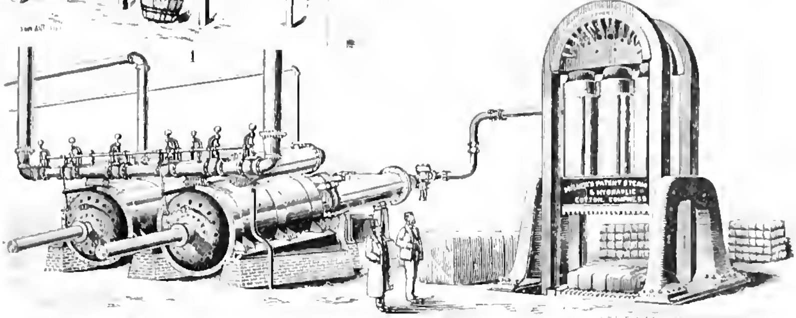
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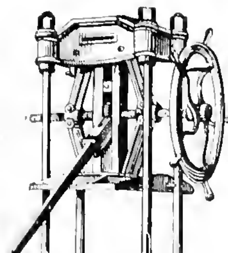
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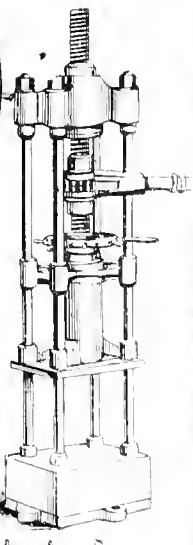
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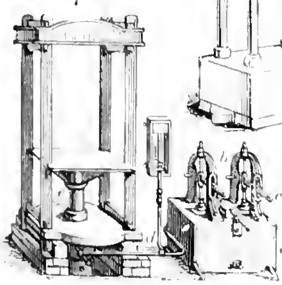
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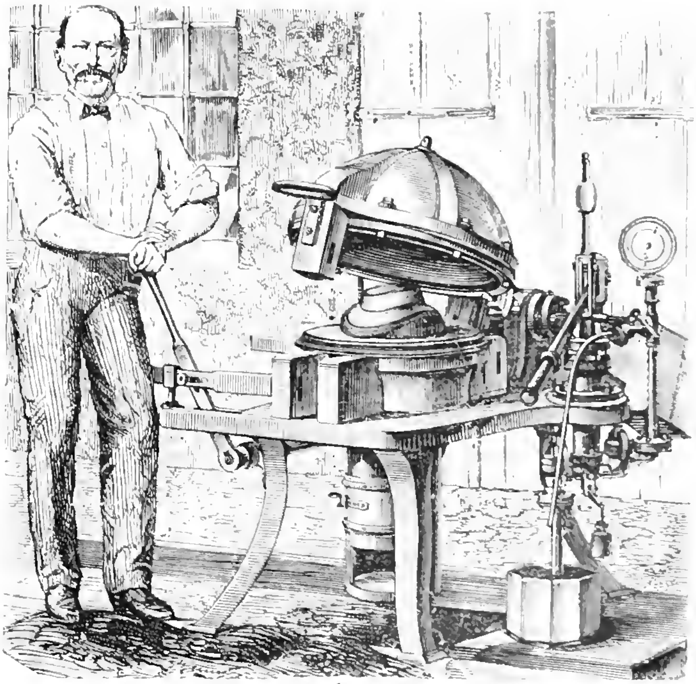
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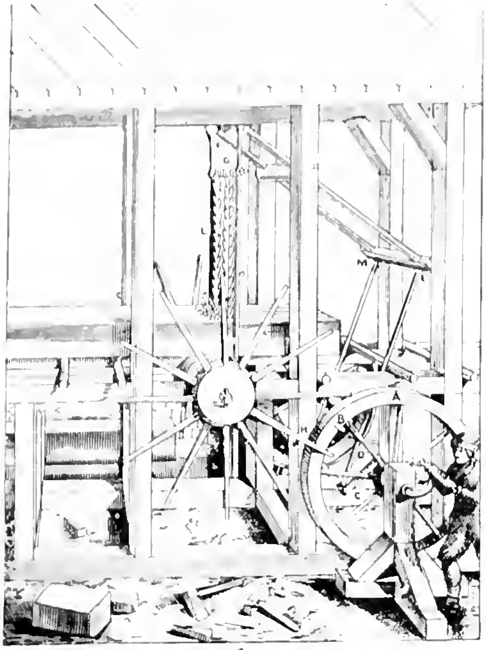
1. Ancient Egyptian wine press. 2. Modern Syrian wine press. 3. Toggle [illegible] 4. [illegible] cider press. 5. Modern hand cider press. 6. Steam and hydraulic cotton compress. [illegible] Boomer toggle packing-press. 8. Differential screw packing-press. 9. Bramah, or hydraulic press. 10. [illegible]



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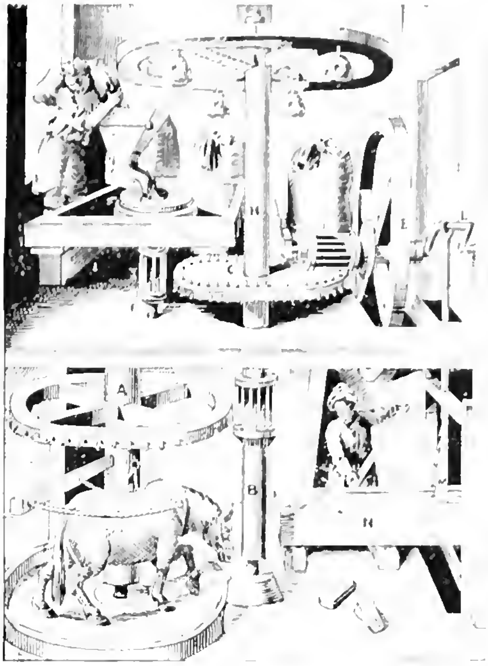

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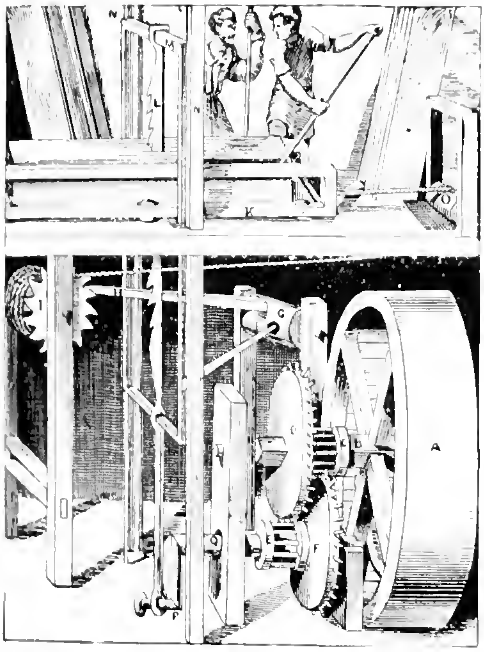

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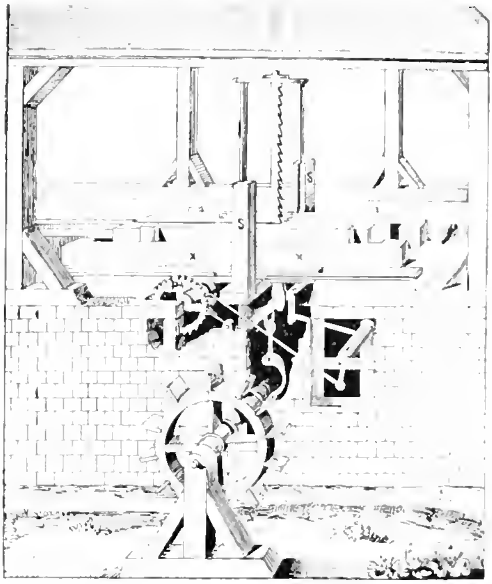

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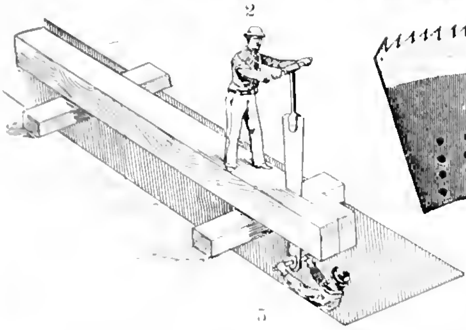

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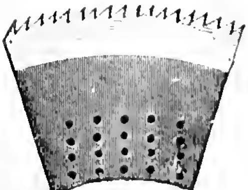

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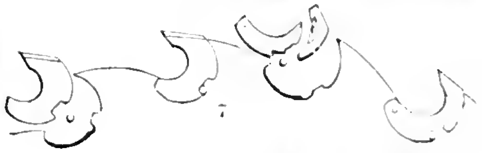

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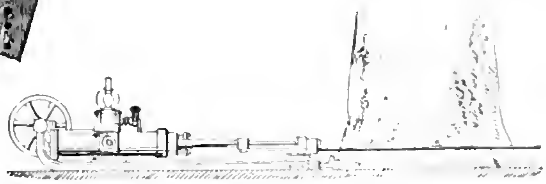

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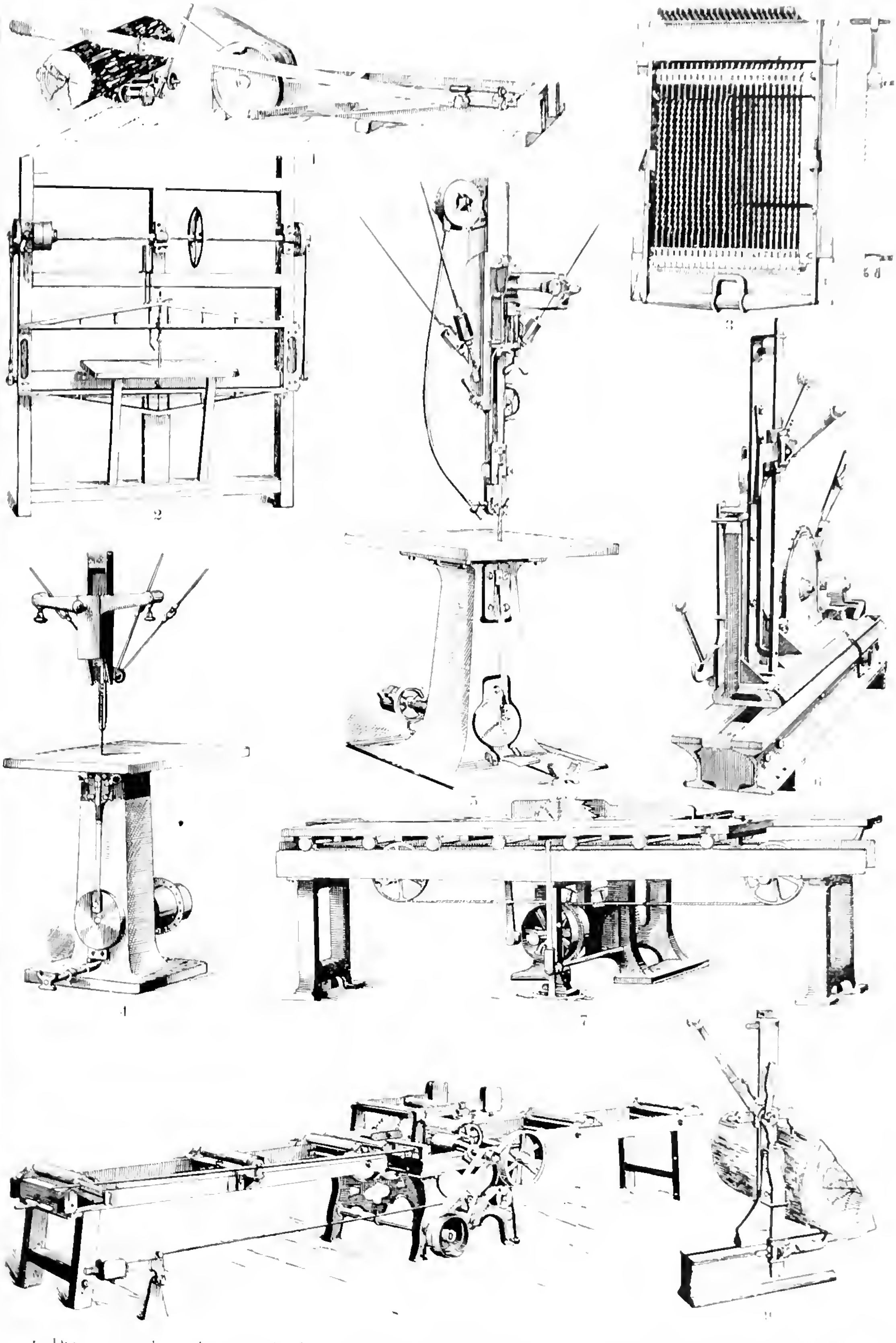
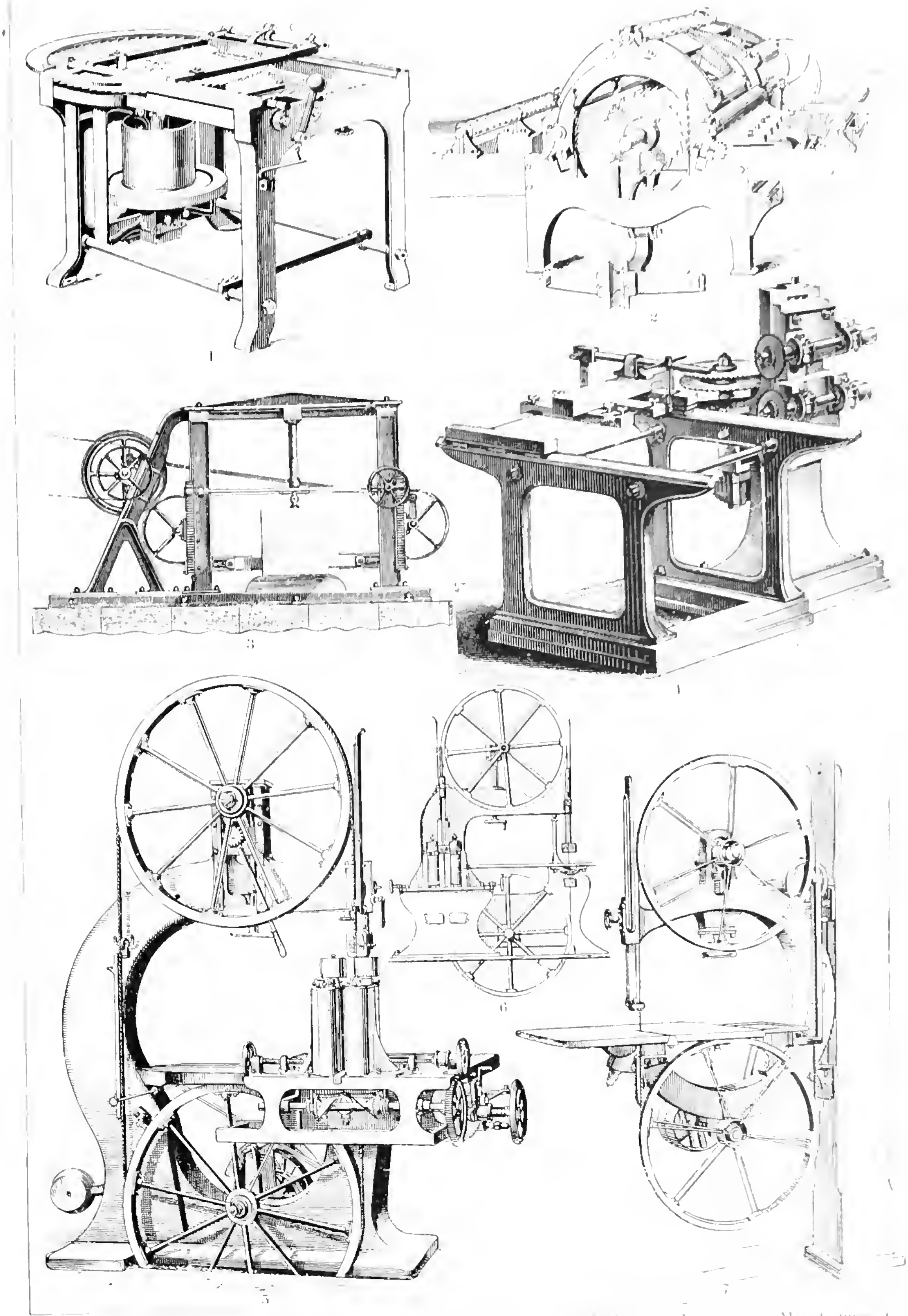
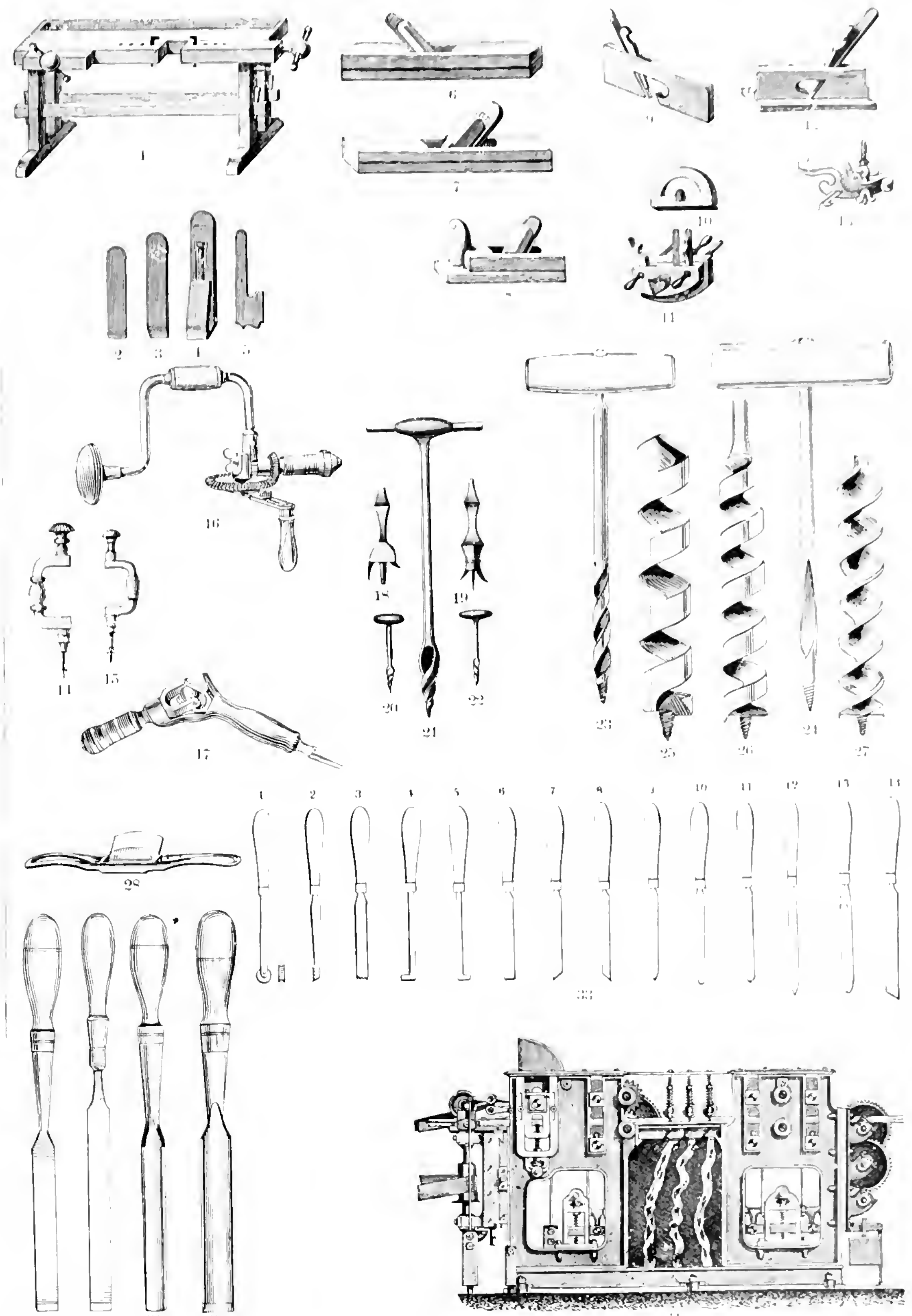
1–4. Mediæval Saw Mills. 1. Hand-power saw mill, 2. Tread wheel power saw mill, 3. Animal-power saw and flour-mill, 4. Water power saw-mill. 5. Pit-saw. 6. "Inserted" saw tooth, 7. "Segmental" saw teeth. 8. Ransome's steam tree felling saw (French).



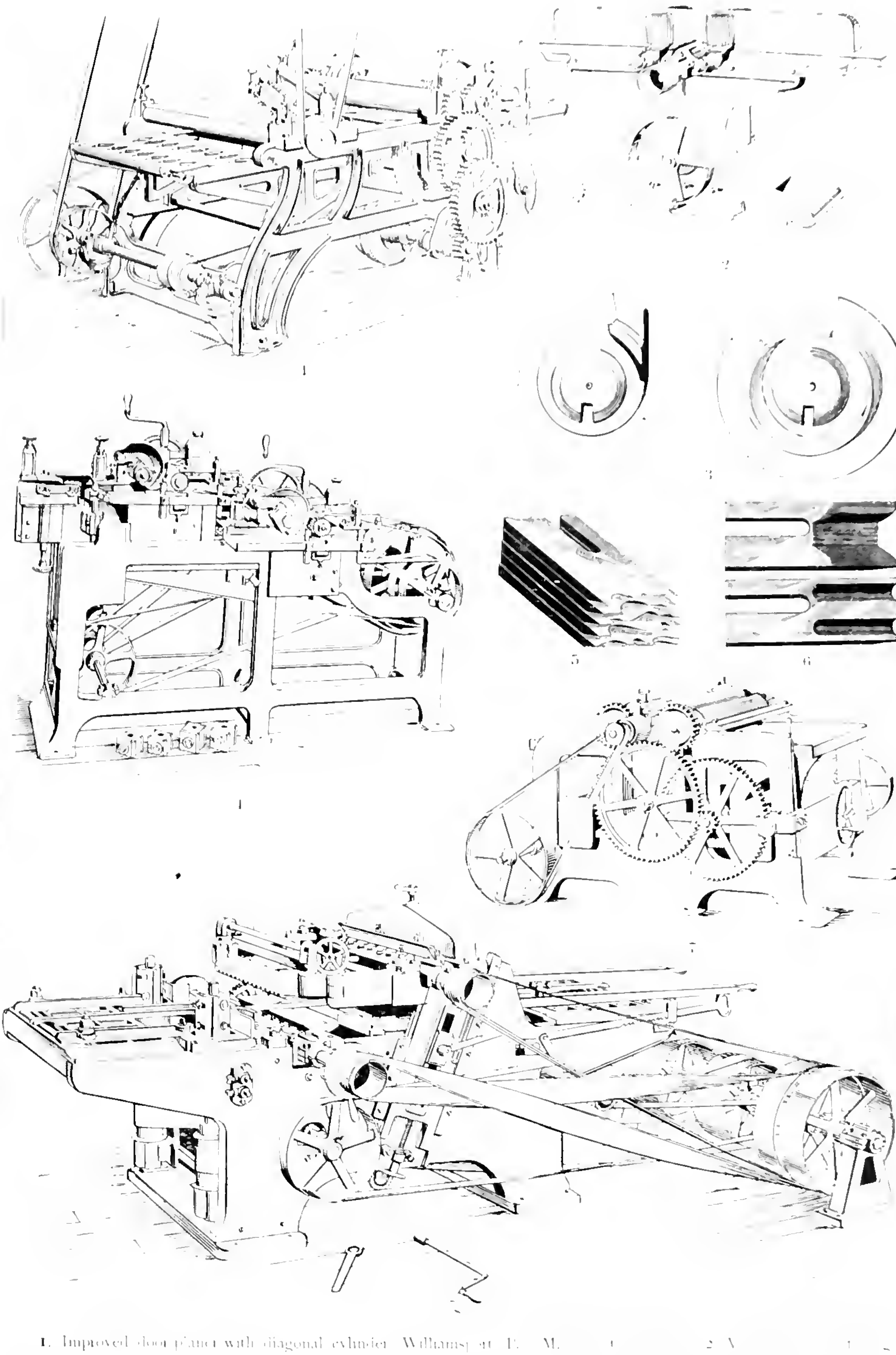
1. Drag-saw machine (Trevor & Co., Lockport, N. Y.). 2. Gate-saw machine (P. Pryibil, New York). 3. Sash gang-saw (Stearns Manufacturing Co., Erie, Pa.). 4. Fret scroll-saw (J. A. Fay & Co., Cincinnati). 5. Improved scroll-saw (Hoyt & Bro. Co., Aurora, Ill.). 6. Improved rack-and-pinion head-block for circular saws (London, Berry & Orton, Philadelphia). 7. Power-feed carriage edging-machine (J. A. Fay & Co.). 8. Self-feed gang ripping-saw (Hoyt & Bro. Co.). 9. Knight duplex mill-dog for circular saws (London, Berry & Orton).



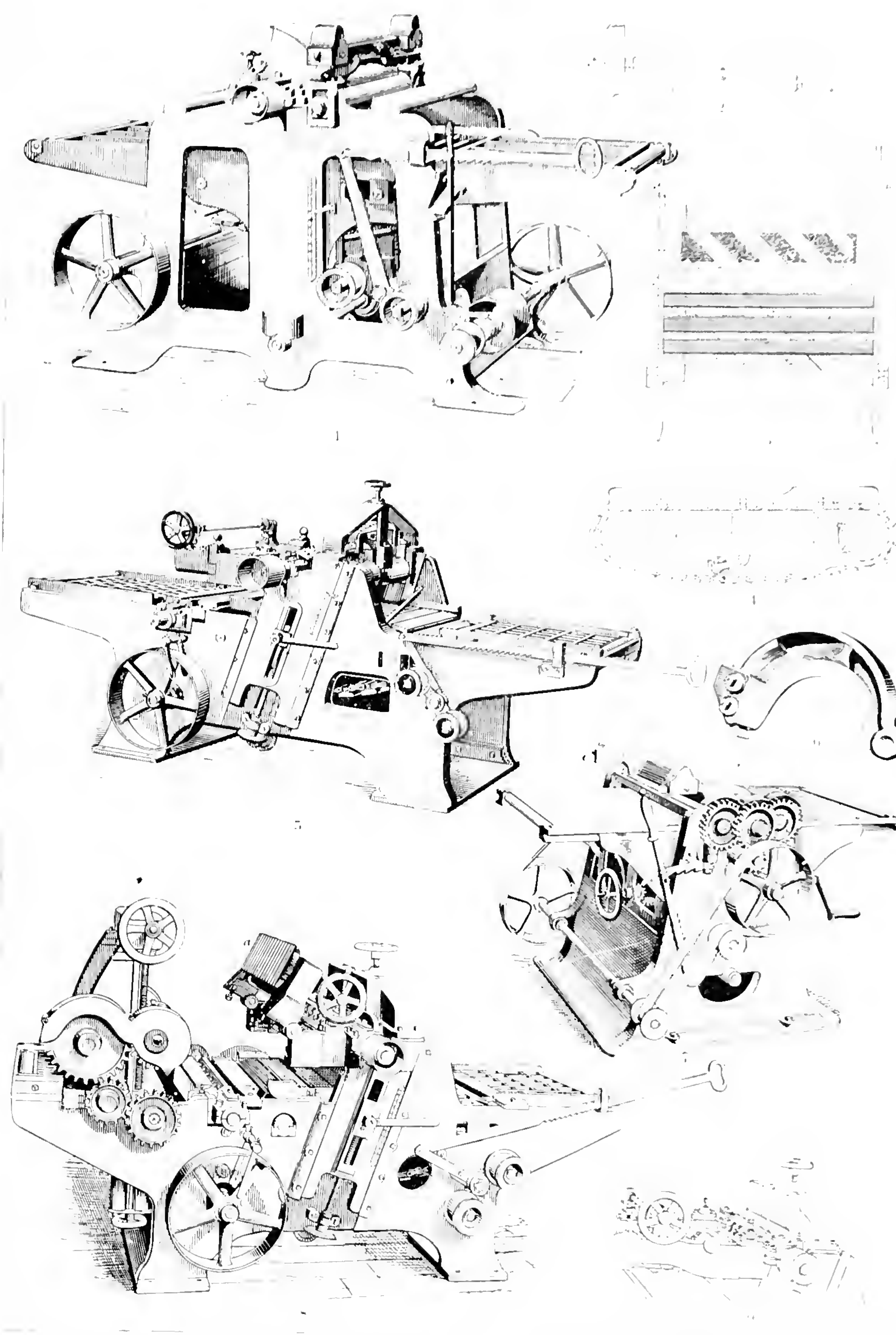
1. Shingle-saw (J. C. Simonds & Son, Grand Rapids, Mich.). 2. Improved edging machine (Stearns Manufacturing Co., Erie, Pa.). 3. Stone-cutting saw. 4. Tenon-saw. 5. Large band re-sawing machine (J. A. Fay & Co., Cincinnati). 6. Combined band re saw and scroll saw (F. & B. Holmes, Buffalo, N. Y.). 7. Post band-saw (Goodell & Waters, Philadelphia).



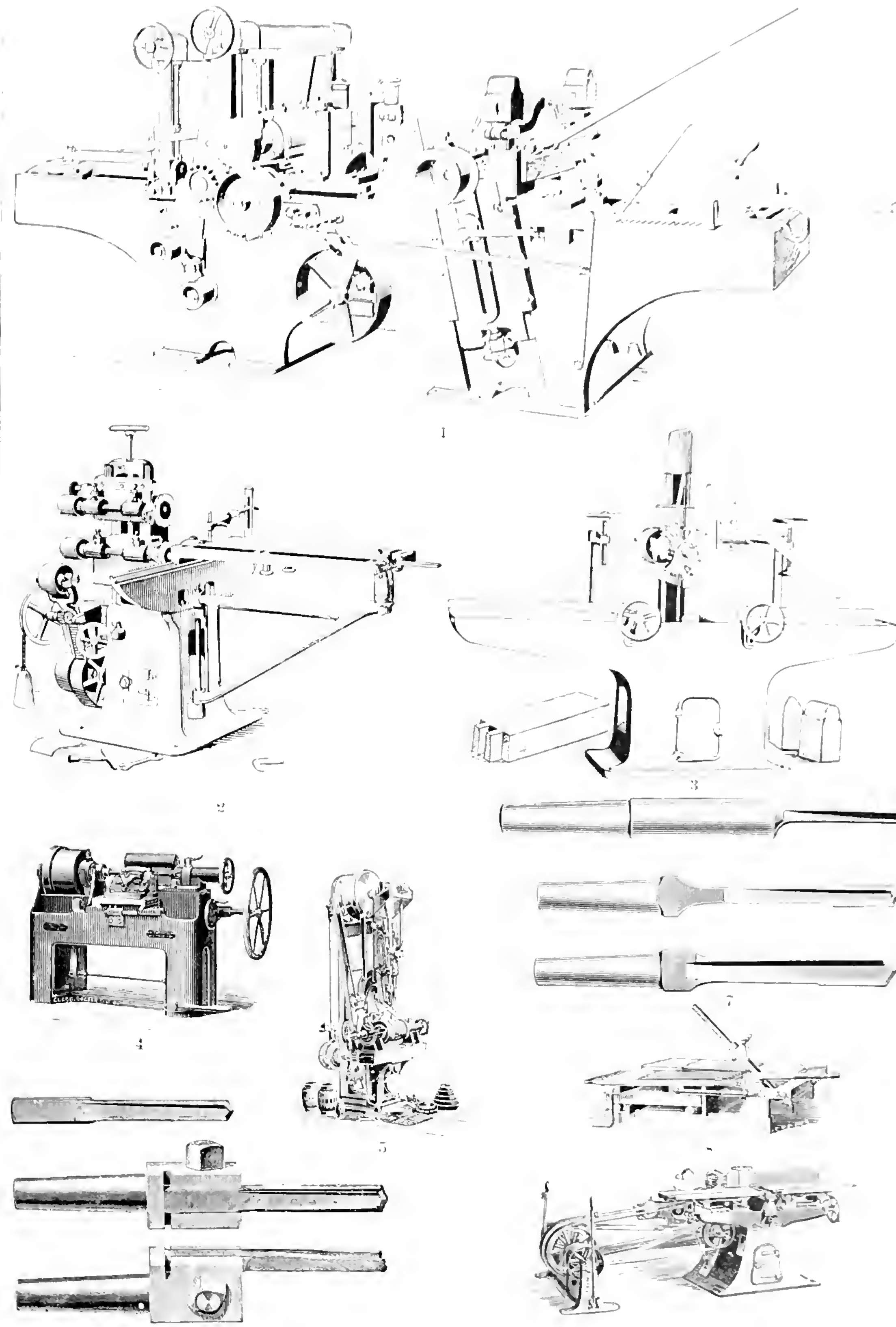
1. Wood-working bench. 2-5. WOOD-PLANE BITS: 2. Jack-plane bit. 3. Smoothing-plane bit. 4. [illegible] 5. Plough or grooving-plane bit. 6-13. WOOD-PLANES: 6, 8. Single-bit smoothing-planes. 7. [illegible] 9. Rebate plane. 10. Router-plane. 11, 13. Grooving-planes. 12. T rebate plane. 14, 15. [illegible] braces. 16. [illegible] 17. Angle-borer. 18. Centre-bit. 19. Bunghole borer. 20, 22. Gimlets. 21. Auger with cross [illegible]. 23. [illegible] cut gimlet. 24. Nail gimlet. 25. Ship-auger with screw. 26. Single twist spur bit. 27. Double twist [illegible]. 28. [illegible] spoke shave. 29. Socket paring chisel. 30. Handled paring chisel. 31. Socket firmer-gouge with outside bevel. 32. Socket firmer gouge with inside bevel. 33. Hand turning tools for ivory, hard wood, and brass. 34. Stationary [illegible] wood planing machine



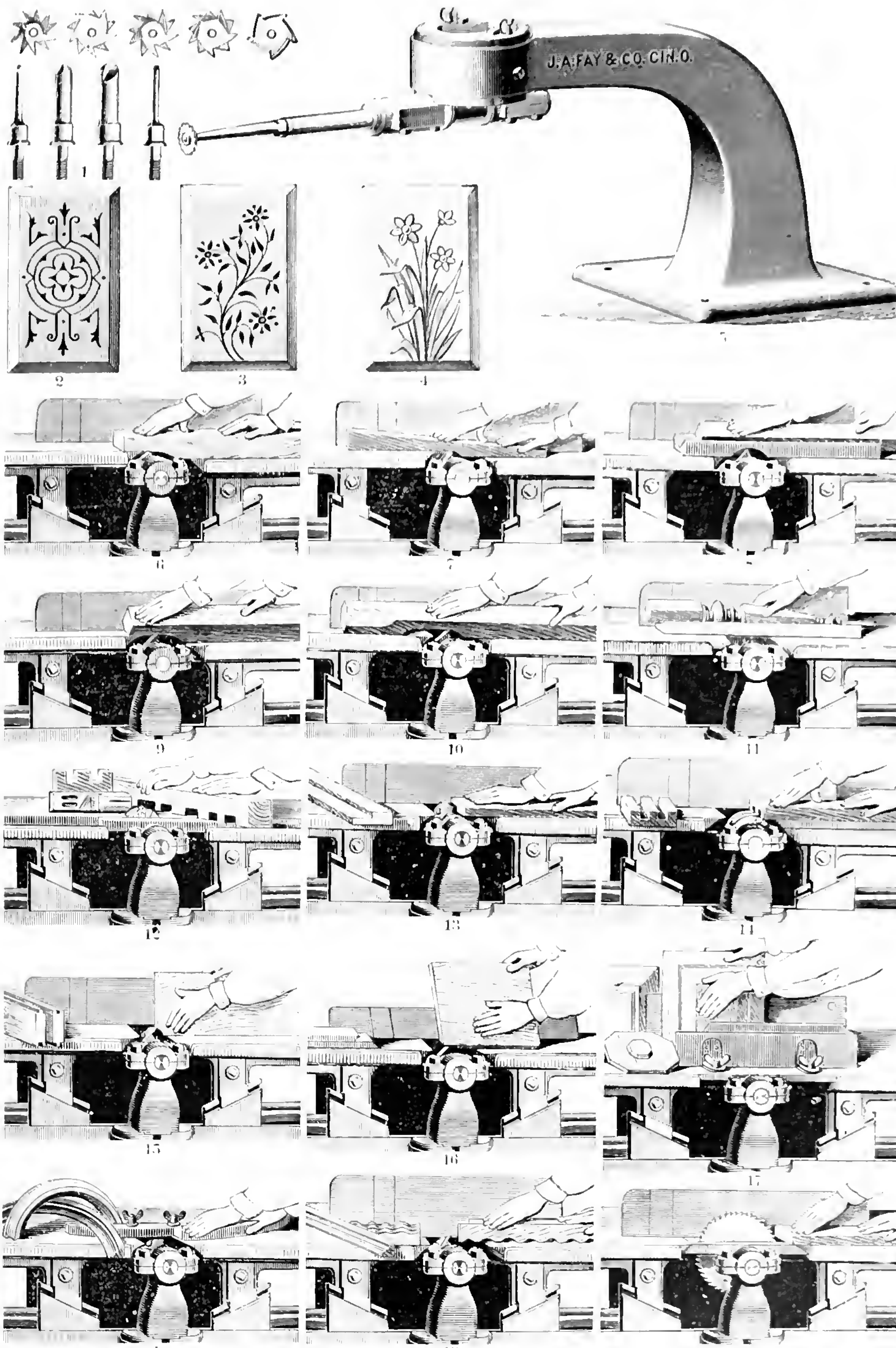
1. Improved door planer with diagonal cylinder (Williamsport [illegible] M[illegible] [illegible]). 2. A[illegible] machine (J. A. Fay & Co., Cincinnati). 3. An old and a new bit. 4. Do[illegible] (J. A. Fay & Co.). 5, 6. Milled bit heads. 7. Improved smoothing planer (J. A. Fay & Co.). 8. Heavy [illegible] dimension planing and jointing machine (J. A. Fay & Co.).



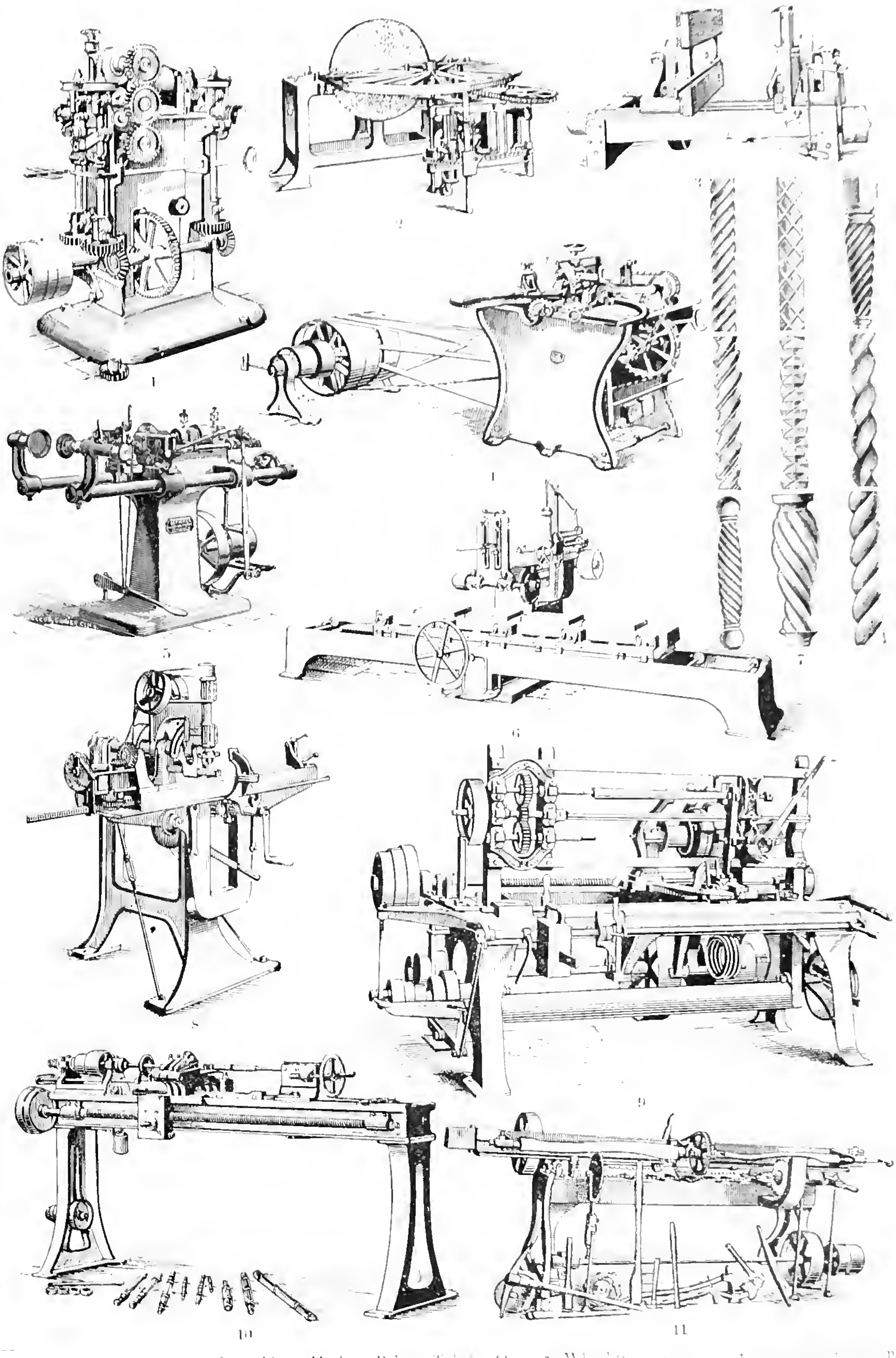
1. Large endless-bed surface planer (J. A. Fay & Co., Cincinnati). 2. [illegible] weighting [illegible] machine. 3. Plan, 4. Elevation, of improved bed for endless-bed surface planers (F. & B. H[illegible]). 5. [illegible] cylinder endless-bed surface-planer (J. A. Fay & Co.). 6. [illegible] 7. [illegible] (J. A. Fay & Co.). 8. Large double-cylinder endless-bed surface planer, [illegible] pressure bar [illegible] while in use (J. A. Fay & Co.).



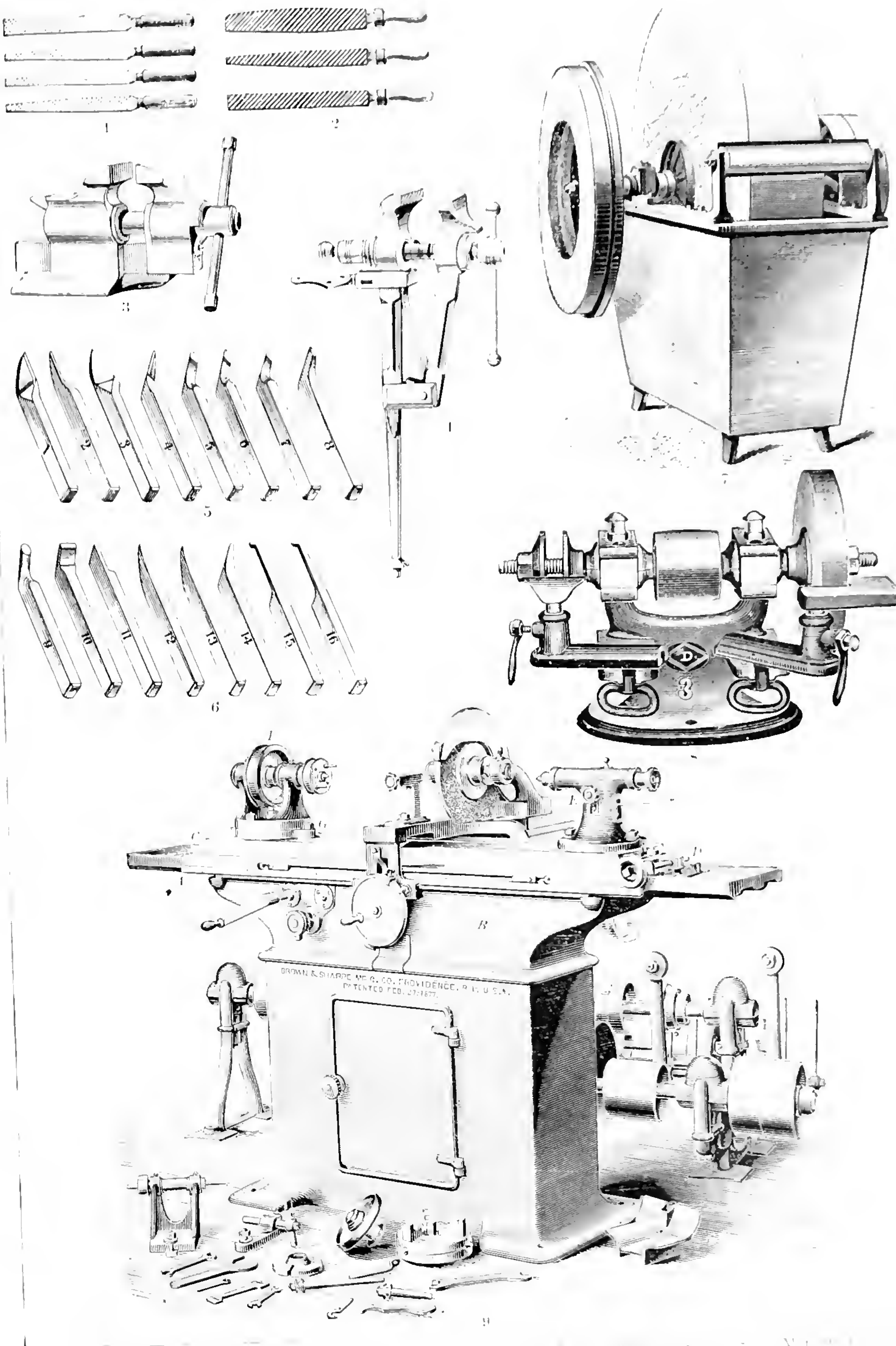
1. Heavy large car-sill and timber-dresser [illegible] 2. [illegible] Egan Co., Cincinnati. 3. Vertical car-tenoning machine, J. A. Fay & Co. 4. [illegible] 5. A double-chisel hub-mortising machine. 6. Adjustable-bit mortising-chisels. 7. [illegible] 8. [illegible] Defiance (Ohio) Machine Works. 9. Universal wood-worker, J. A. Fay & Co.



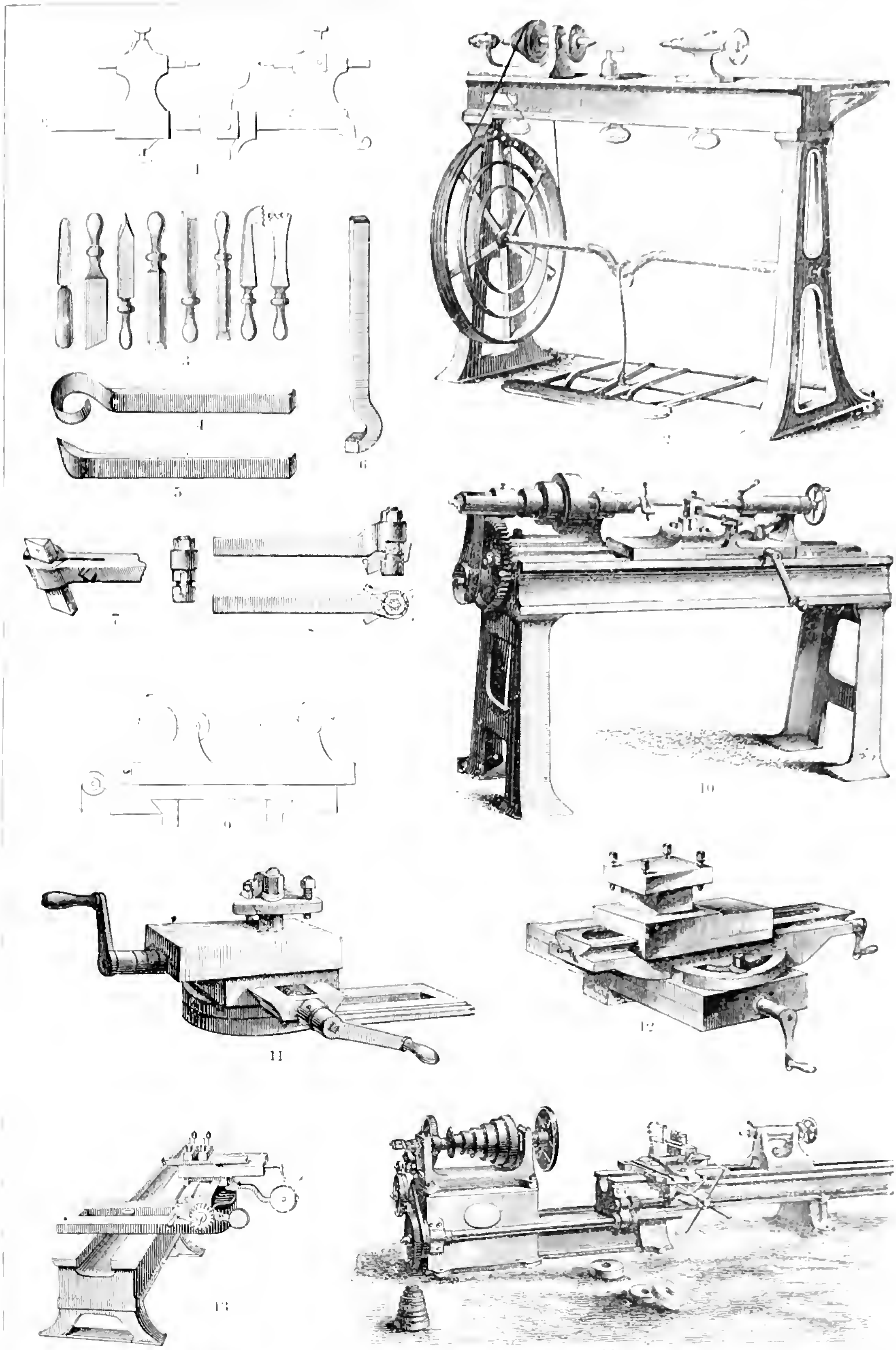
1. Cutters and tracing tools, 2–4. Ornamented work, 5. Perspective, of [illegible] J. A. F[illegible] Co., Cincinnati. 6–20. Operations of the "Universal" wood worker J. A. Fay & C[illegible] 7. [illegible]ing, 8. Box chamfering, 9. Cornering, 10. Chamfering, 11. Squaring up newels, 12. [illegible] 14. Ploughing, 15. Hand matching, 16. Jointing and mitering, 17. Raising door-panels, 18. [illegible] Ma[illegible] waved mouldings, and 20. Ripping.



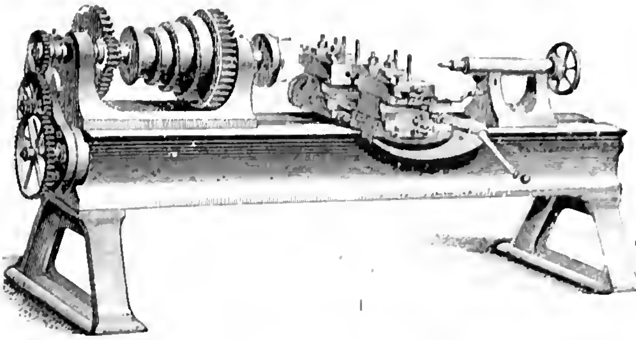
1. Rod, pin, and dowel machine (Herbert Baker, Toledo, O.). 2. Wh[illegible] (Bentel, Margedant & Co., Hamilton, O.). 3. Drawer-fitting machine (Egan & C[illegible] (Bentel, Margedant & Co.). 5. Wheel-tenoning machine. 6. Automatic [illegible] Cincinnati). 7. Work, 8. Perspective, of Prybil's twist machine (P. Pryb[illegible], New York [illegible] lathe. 10. Automatic gauge-lathe (J. A. Fay & Co.). 11. Improved [illegible] Fr[illegible], N. Y.



1. Double-cut, 2. Single-cut, files. 3. Parallel filing-vise. 4. S[illegible] 5. [illegible] tools. 7. Ordinary power grindstone. 8. Two-wheel grinding-machine [illegible] versal grinding machine (Brown & Sharpe Manufacturing Co., Prov[illegible]



1. Turn-bench. 2. Foot-lathe. 3. Wood-working foot-lathe tools. 4. W[illegible] 5. [illegible]ing lathe-tools. 9. Cross-section of copying-lathe. 10. Simple form of [illegible] 11, 12. [illegible] for power lathes. 13. Curved slide-rest. 14. Gap-bed lathe.



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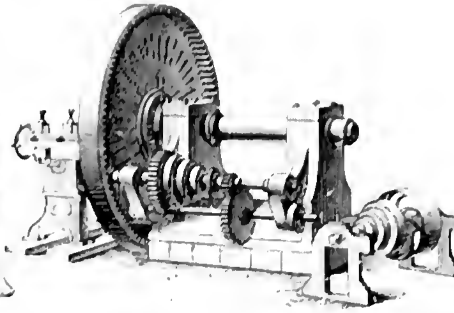

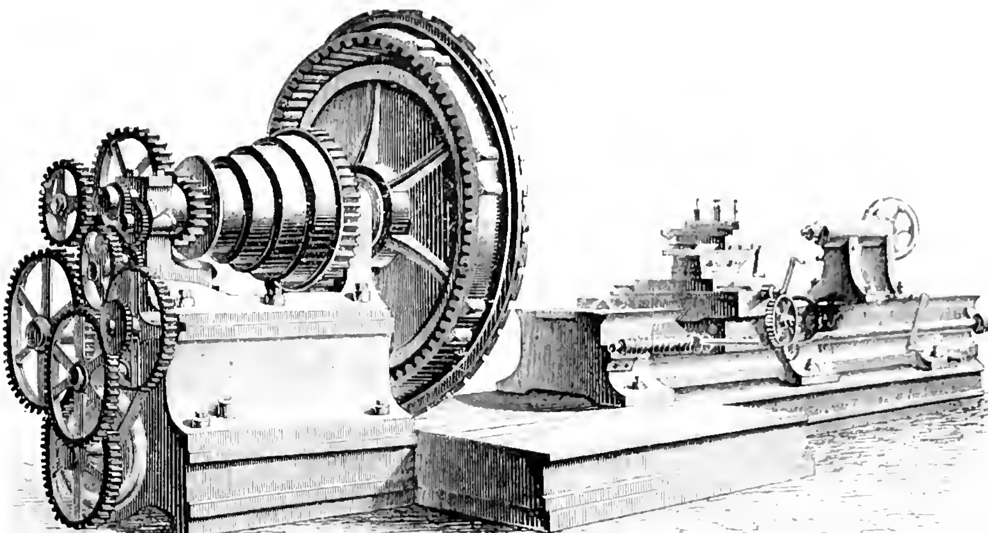

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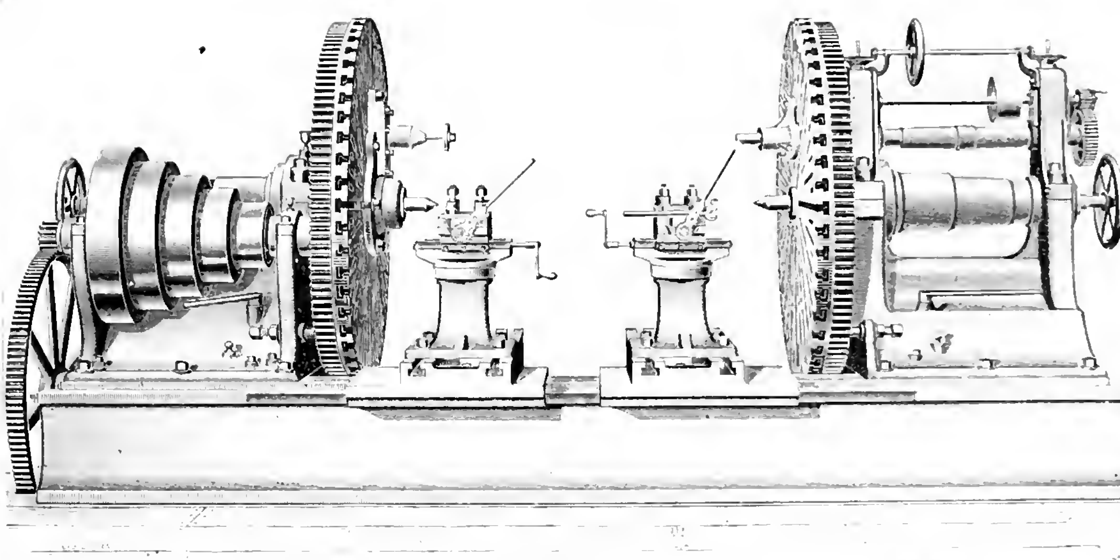

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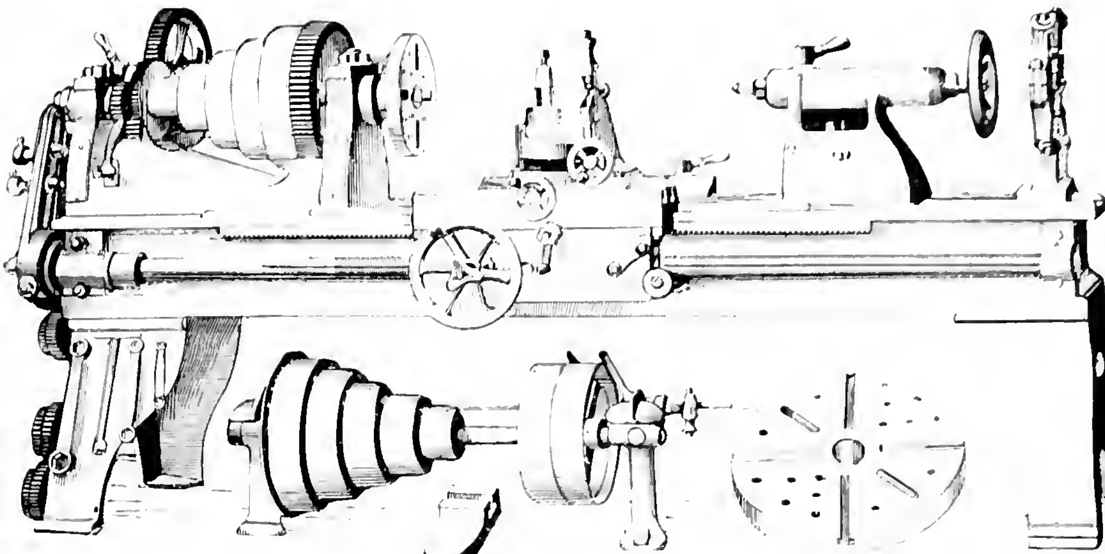
1. Double tool lathe. 2, 3. Face plate lathe. 4. 70 inch swing [illegible] Machine Co., Fitchburg, Mass.)



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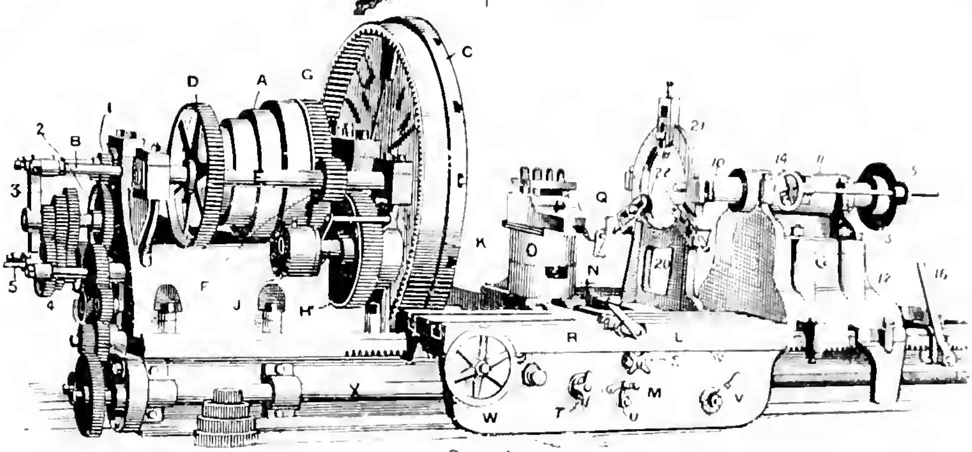

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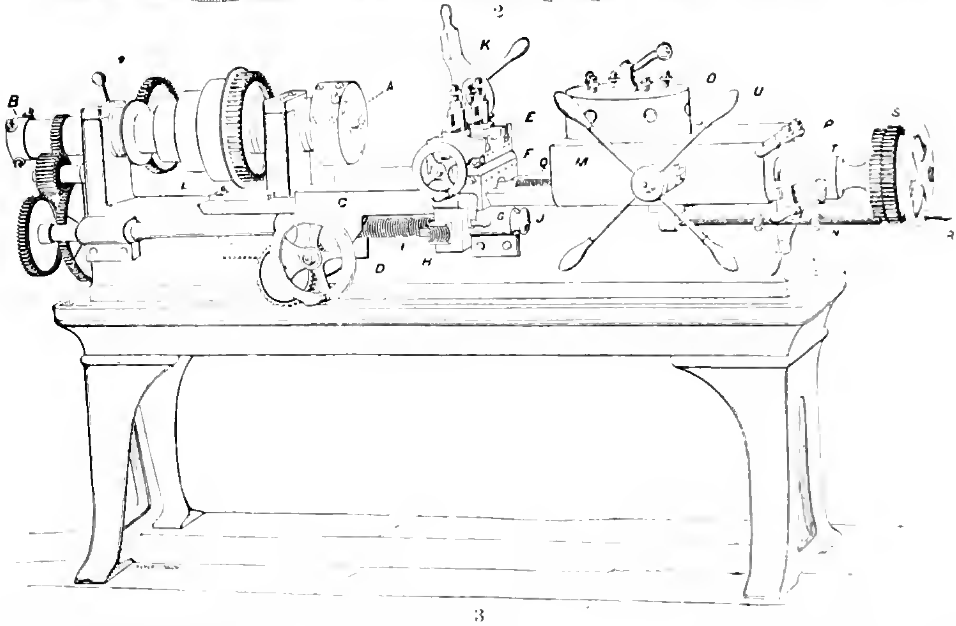
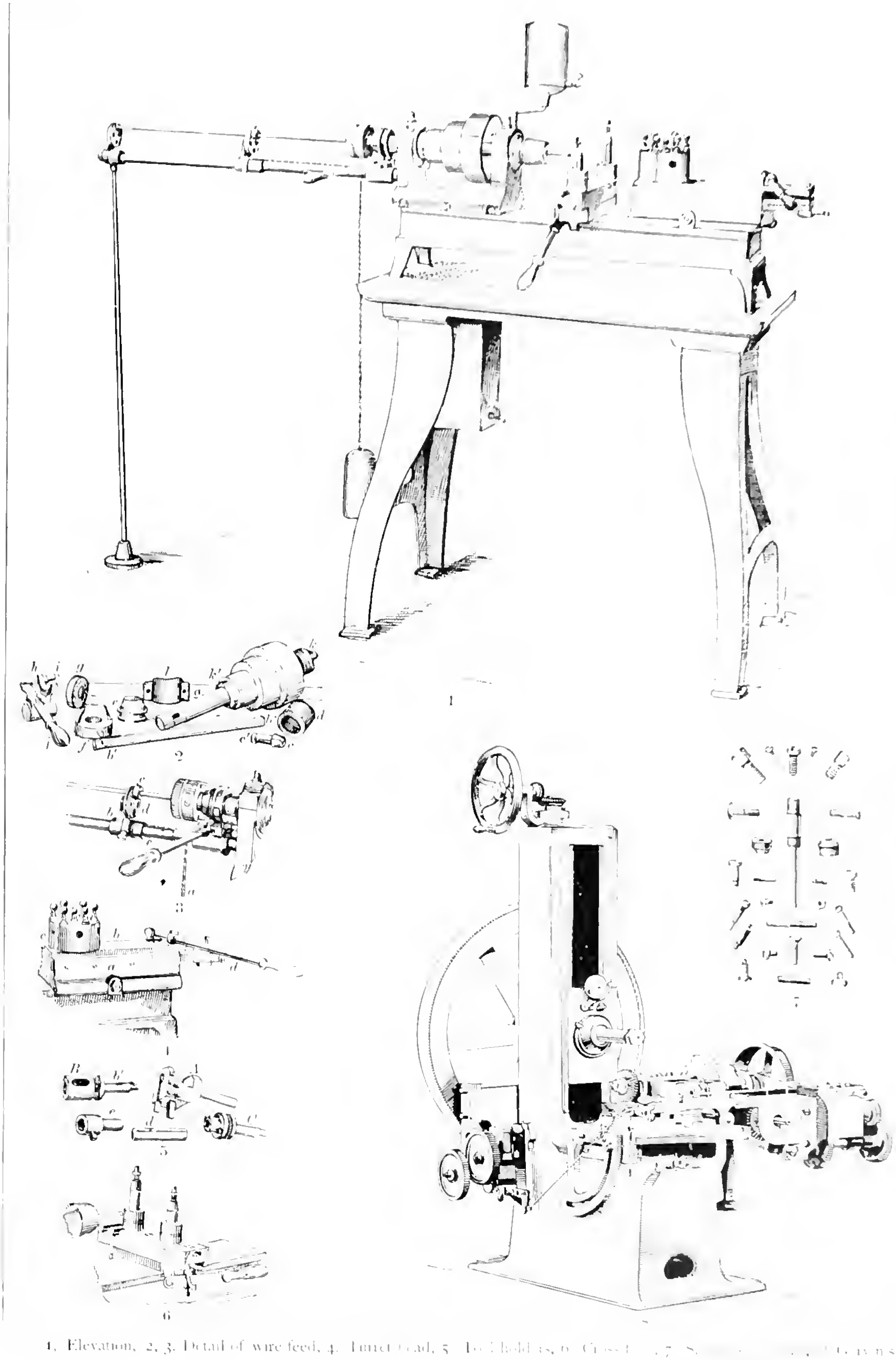
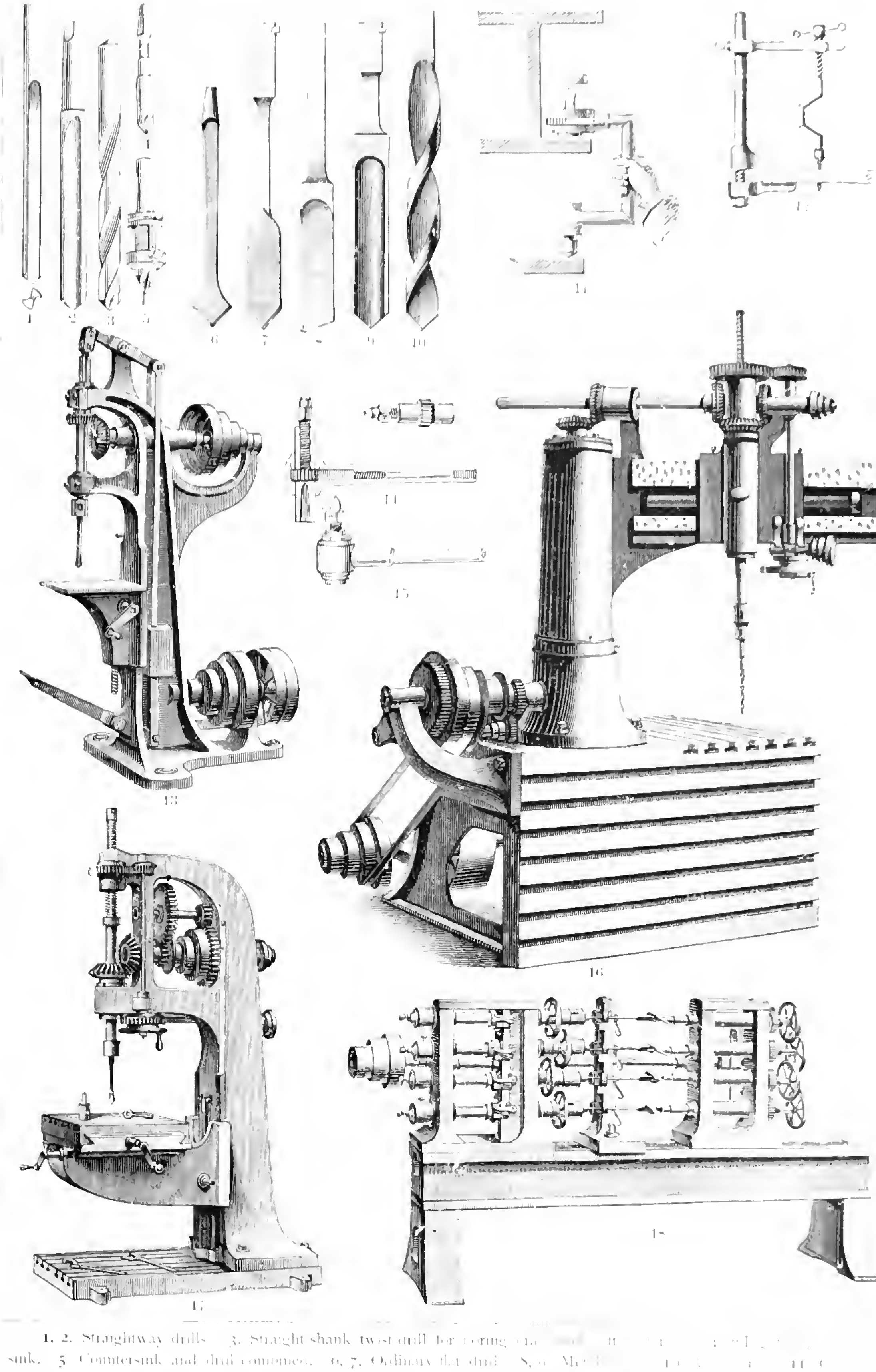


3

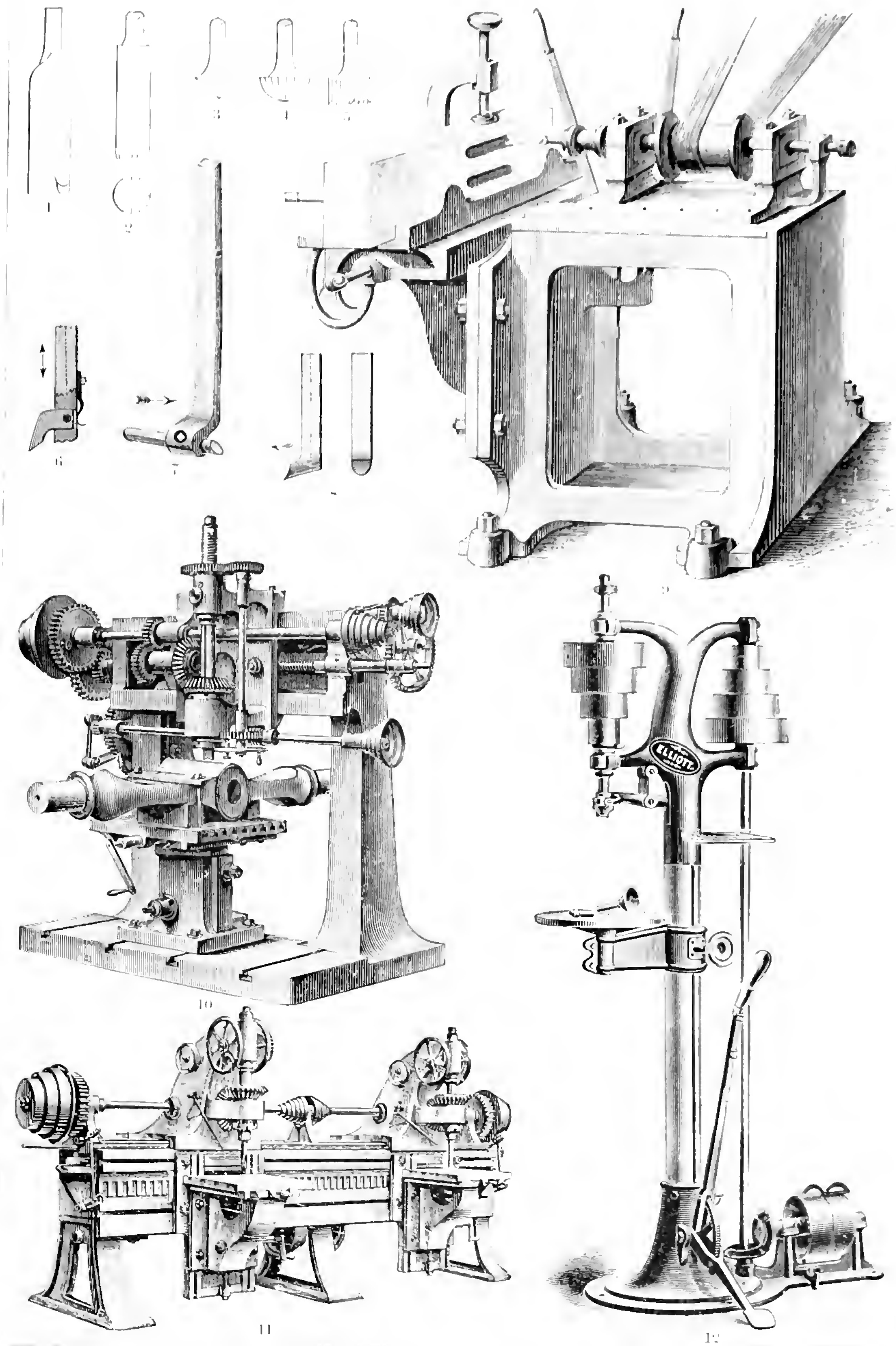
1. Improved engine-lathe (Gould & Eberhardt, Newark, N. J.). 2. 62-inch screw-cutting [illegible] Wilmington, Del.). 3. Niles screw-cutting machine (Niles Tool Works, Hamilton, O.)



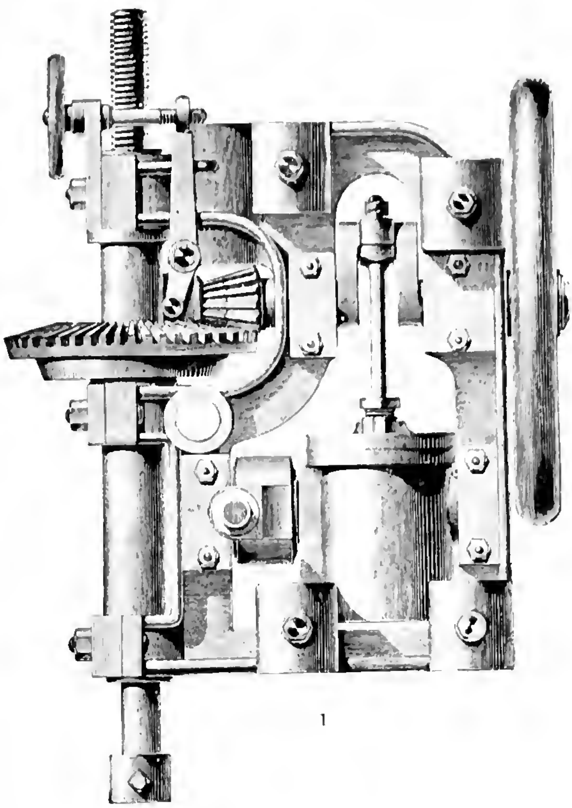
1, Elevation, 2, 3. Detail of wire feed, 4. Turret head, 5. Tool holders, 6. Cross [illegible], 7. S[illegible] Garvin's screw cutting machine (E. E. Garvin & Co., New York). 8. Automatic gear cutter (Gould & [illegible], Newark, N. J.).



1, 2. Straightway drills. 3. Straight shank twist drill for boring [illegible] 5. Countersink and drill combined. 6, 7. Ordinary flat drill. 8, 9. M[illegible] 11. [illegible] cranks and ratchet brace. 12. Crank brace. 13. Vertical power drilling [illegible] 14. [illegible] 15. Elevation of ratchet drill. 16. Radial drilling machine. 17. Vertical automatic [illegible] 18. [illegible] horizontal drilling machine.



1. Double-pointed drill. 2. Rose-bit. 3–5. Reamer-bits. 6. S. [illegible] 9. [illegible] 10,
11. Cotter-drills for metal. 12. Drill-press (Sterling Elliott, Newton, Mass.).



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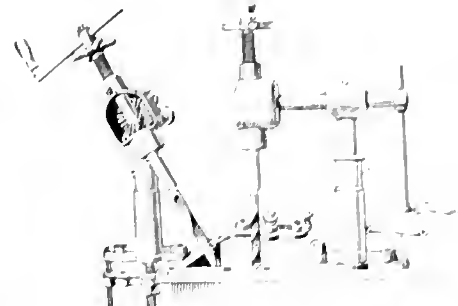

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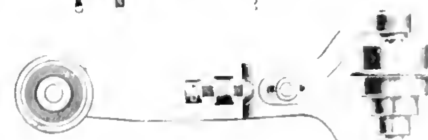

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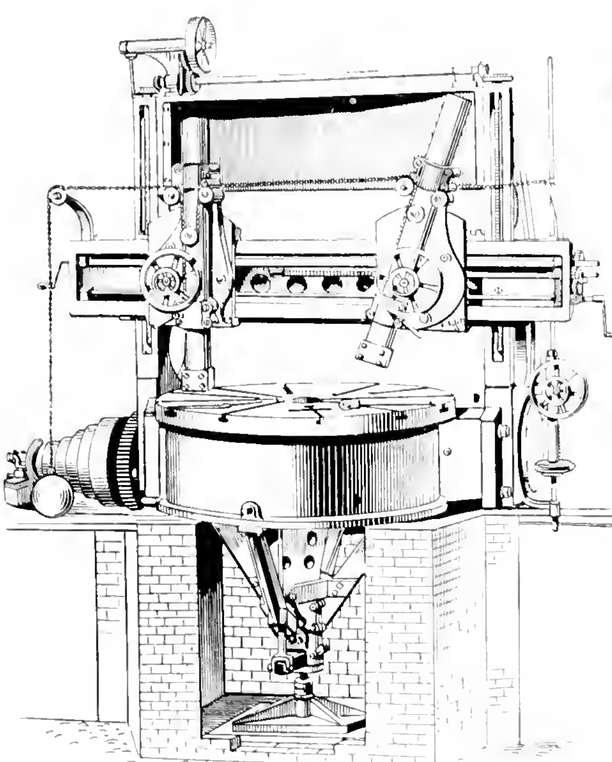

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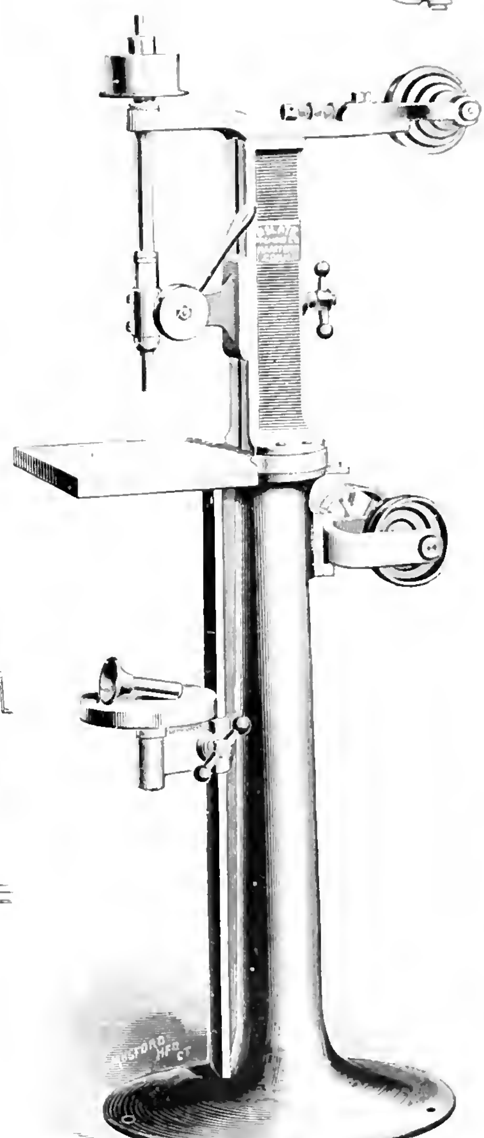
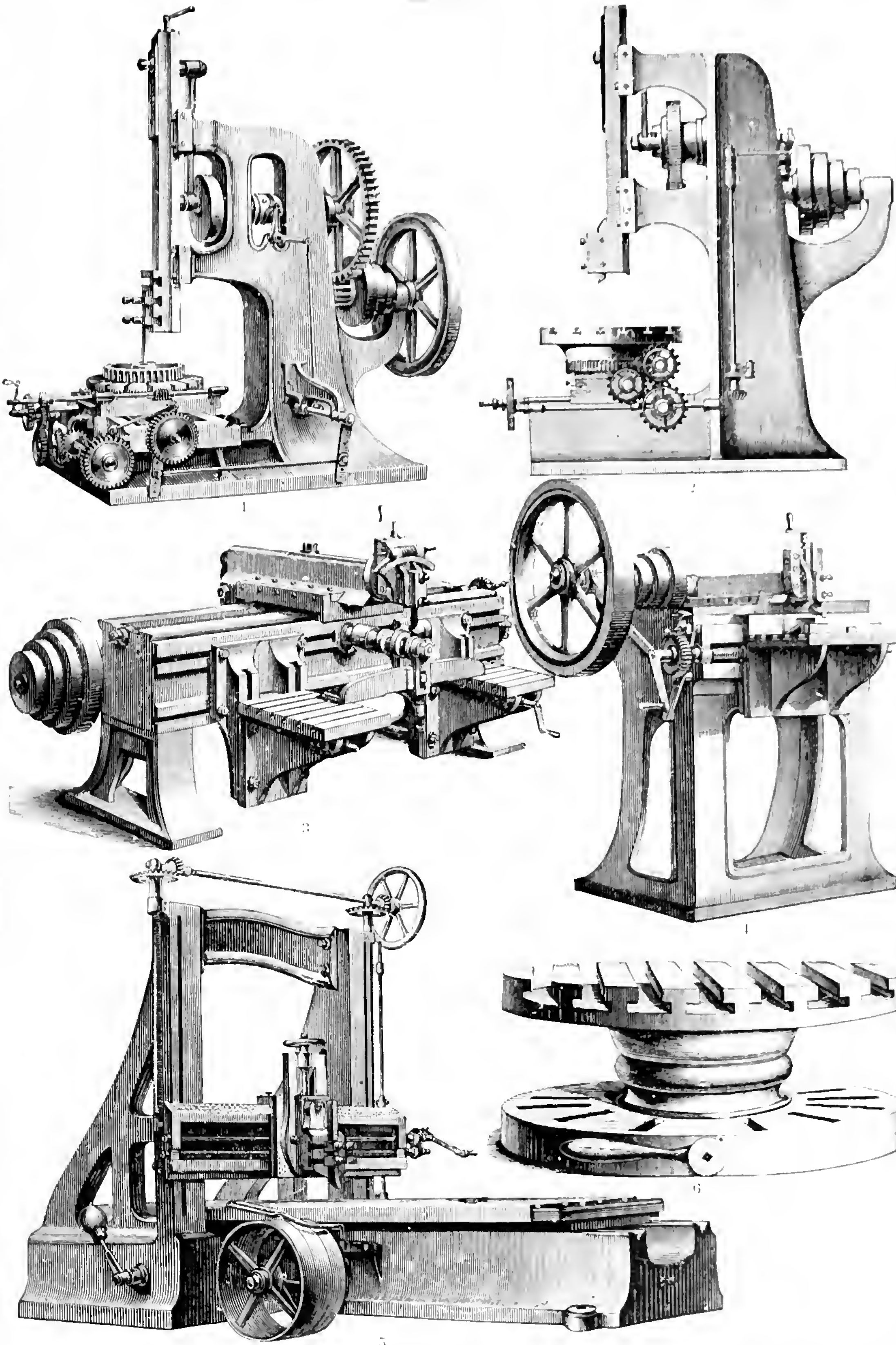
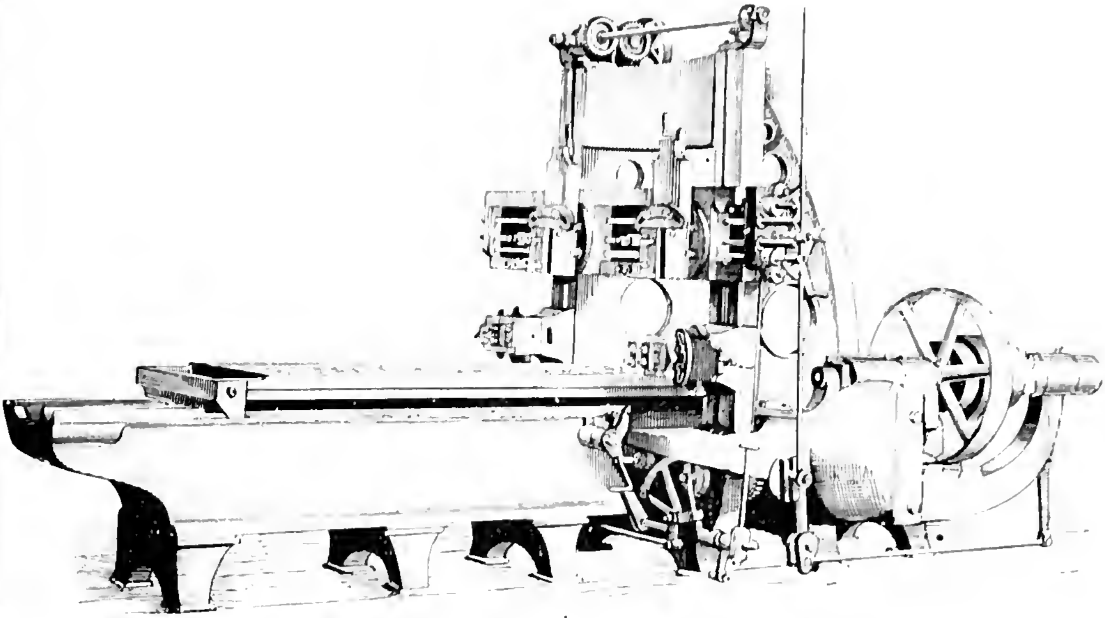


5

1. Single-spindle vertical drill with motor attached. 2. Boring- and turning-mill (Niles [illegible] W[illegible] H[illegible]). 3. Hand-drill in two positions. 4. Plan of top arm of drill-frame. 5. Elevation of the "Se[illegible] [illegible] P[illegible] Hartford, Conn.).



1, 2. "Slotters," or vertical planing machines. 3, 4. "Shapers," or [illegible]
5. "Planer," or horizontal planing machine with stationary tool. 6. Table of a new varie[illegible] or "shaper."



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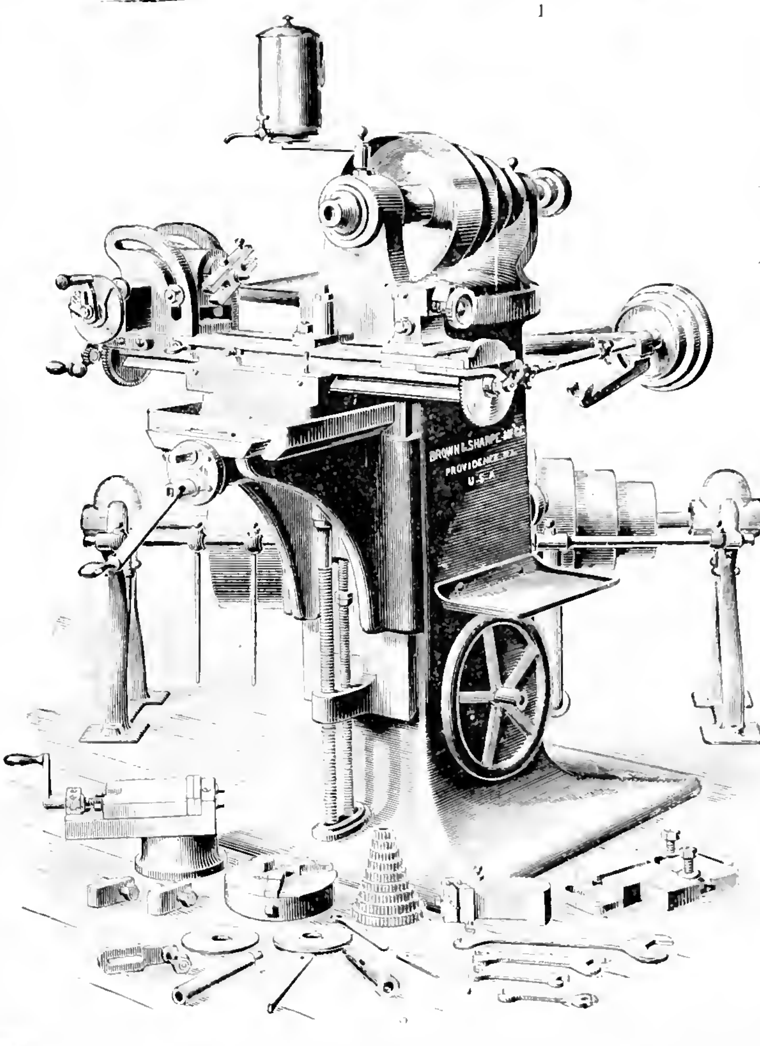

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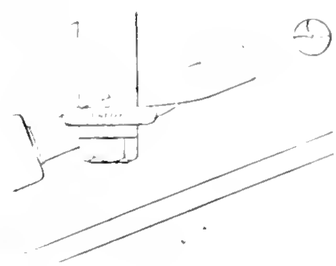

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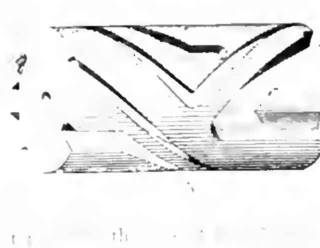
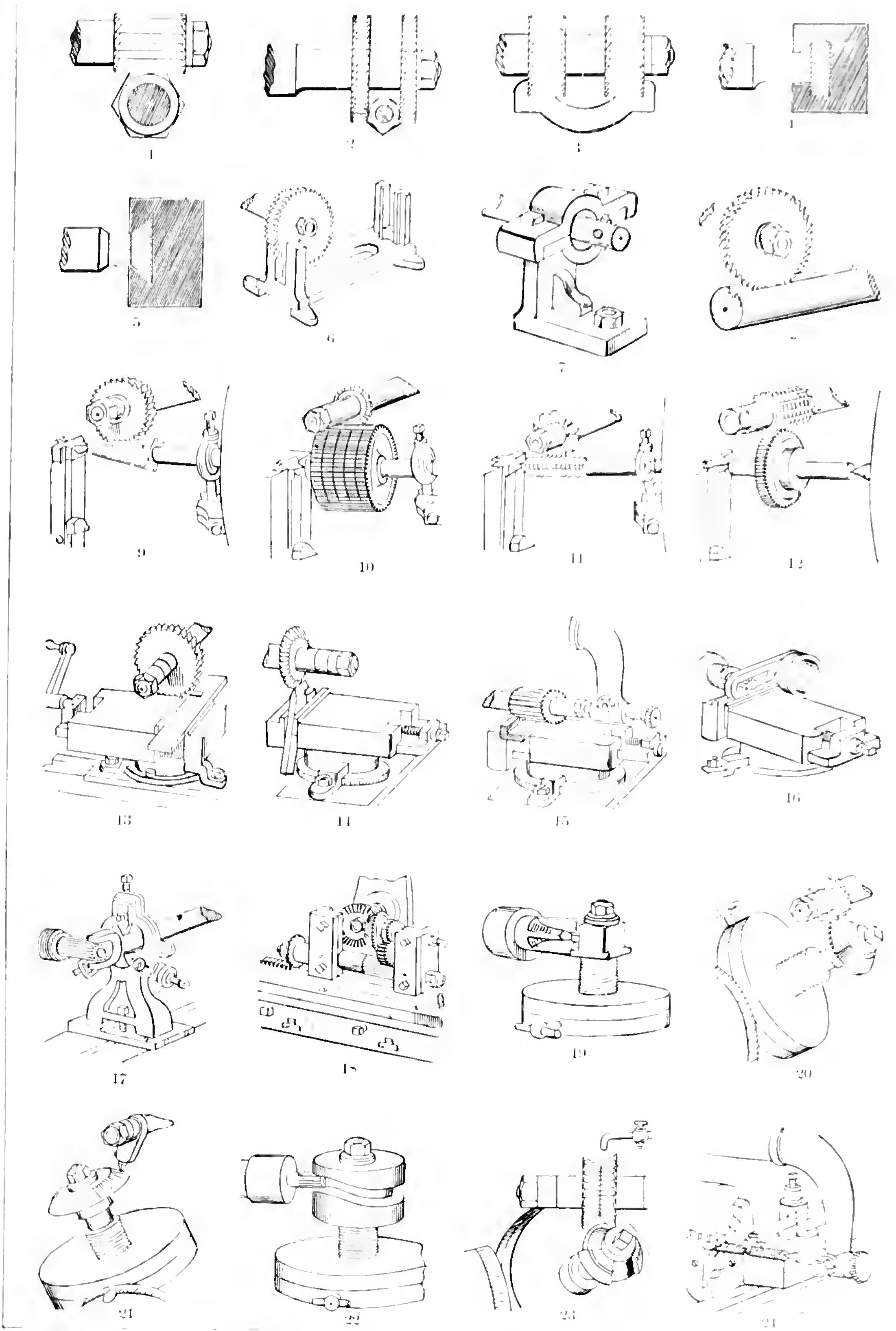
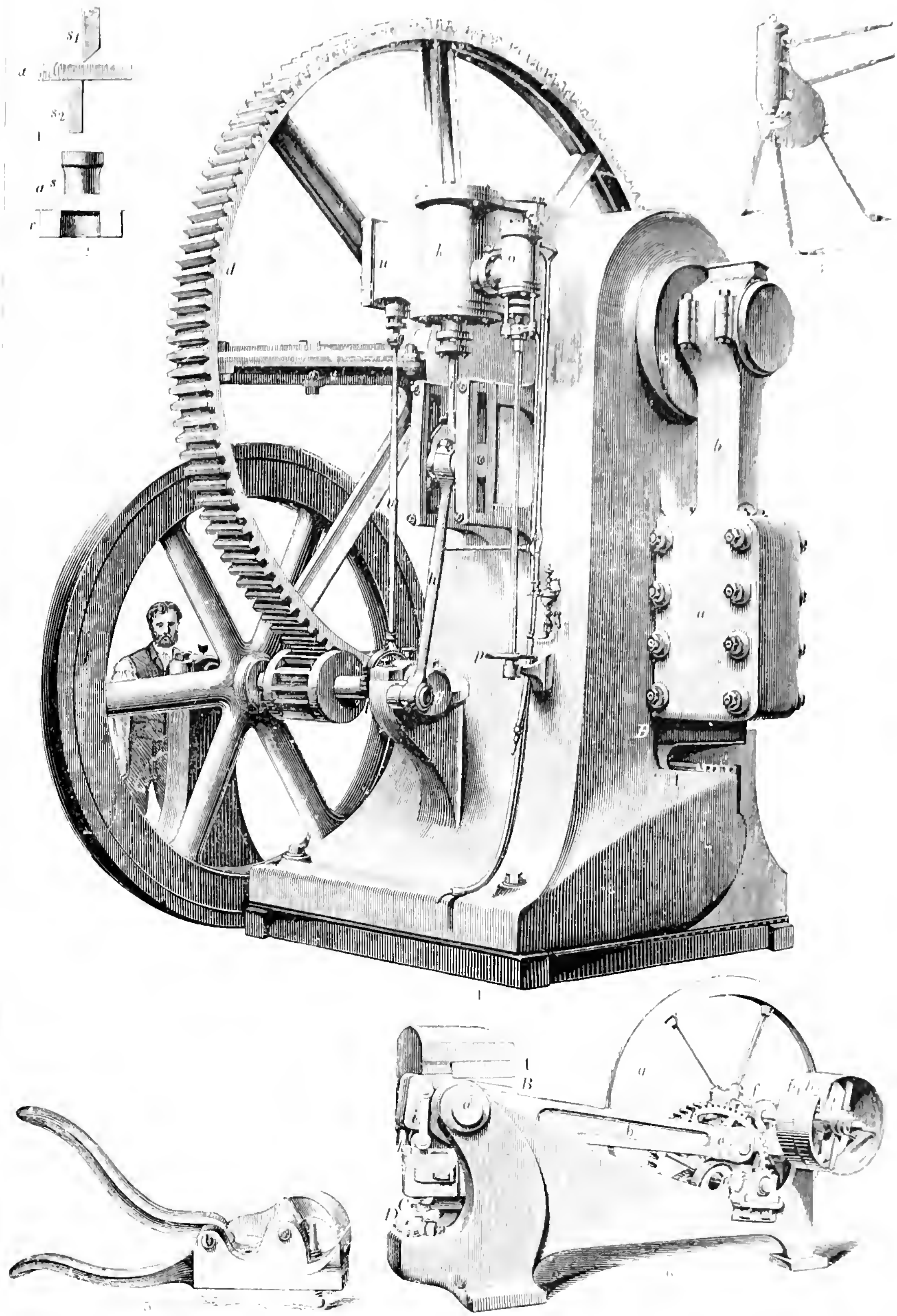


5

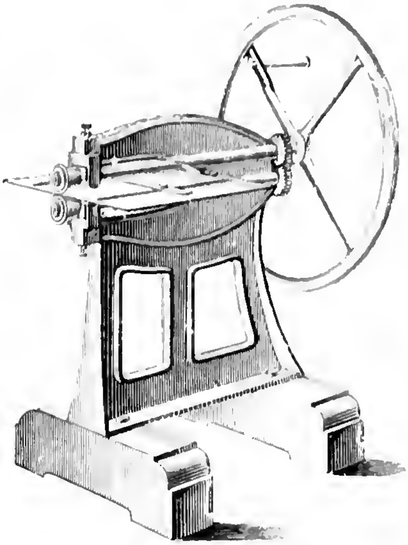
1. Sellers' planing-machine, with four stationary tools for simultaneously work[illegible] (Wm. Sellers & Co., Philadelphia). 2. Perspective, 3–5. Work[illegible] Manuf'g Co., Providence, R. I.)



1–24. MILLING OPERATIONS: 1. Milling hexagon nuts or bolt heads, 2. M[illegible], 3. Milling a number of caps, 4. Milling a T slot, 5. Milling a V slot, 6. Milling [illegible], 7. M[illegible] boring-bar arbor, 8. Milling a key seat, 9. Milling a taper-reamer, 10. Milling a [illegible], 11. M[illegible], 12. Hobbing a worm wheel, 13. Cutting off pieces of metal, 14. Milling a thread [illegible], 15. M[illegible], 16. M[illegible]ing a slot, 17. Milling a fork tine with its round shank, 18. Cutting a rack, 19. M[illegible], 20. M[illegible] an angular cutter, 21. Indexing a dial-plate, 22. Milling a cam, 23. M[illegible], 24. Cutting off round or square stock.



SHEARS AND PUNCHES:—1. Cutting action of [illegible] 2. Pu[illegible] 3. H[illegible] 4. [illegible]worth's parallel shear with attached motor. 5. [illegible] 6. [illegible]



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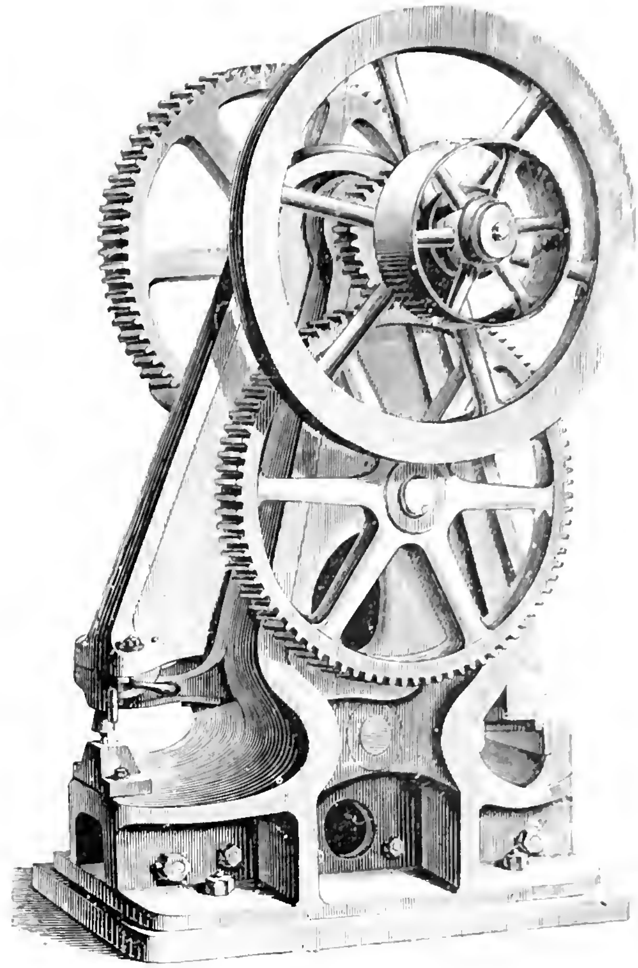

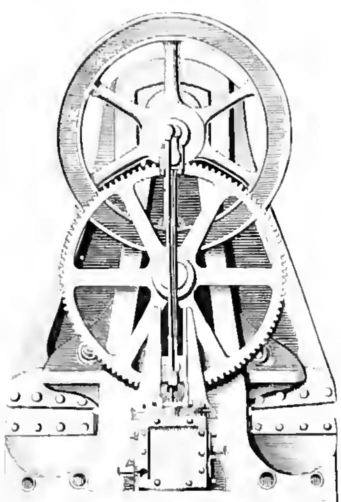

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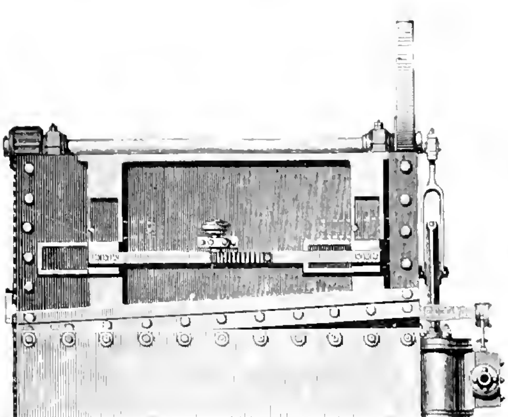

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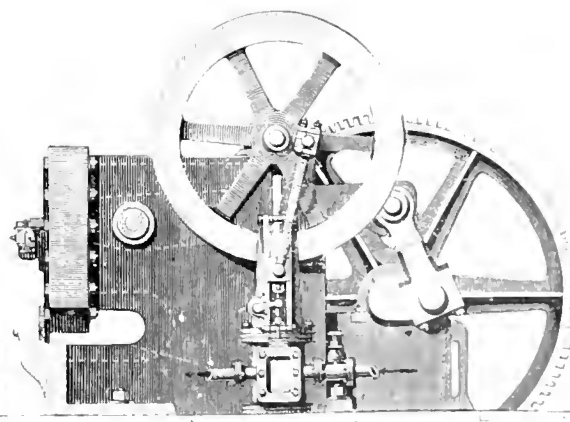
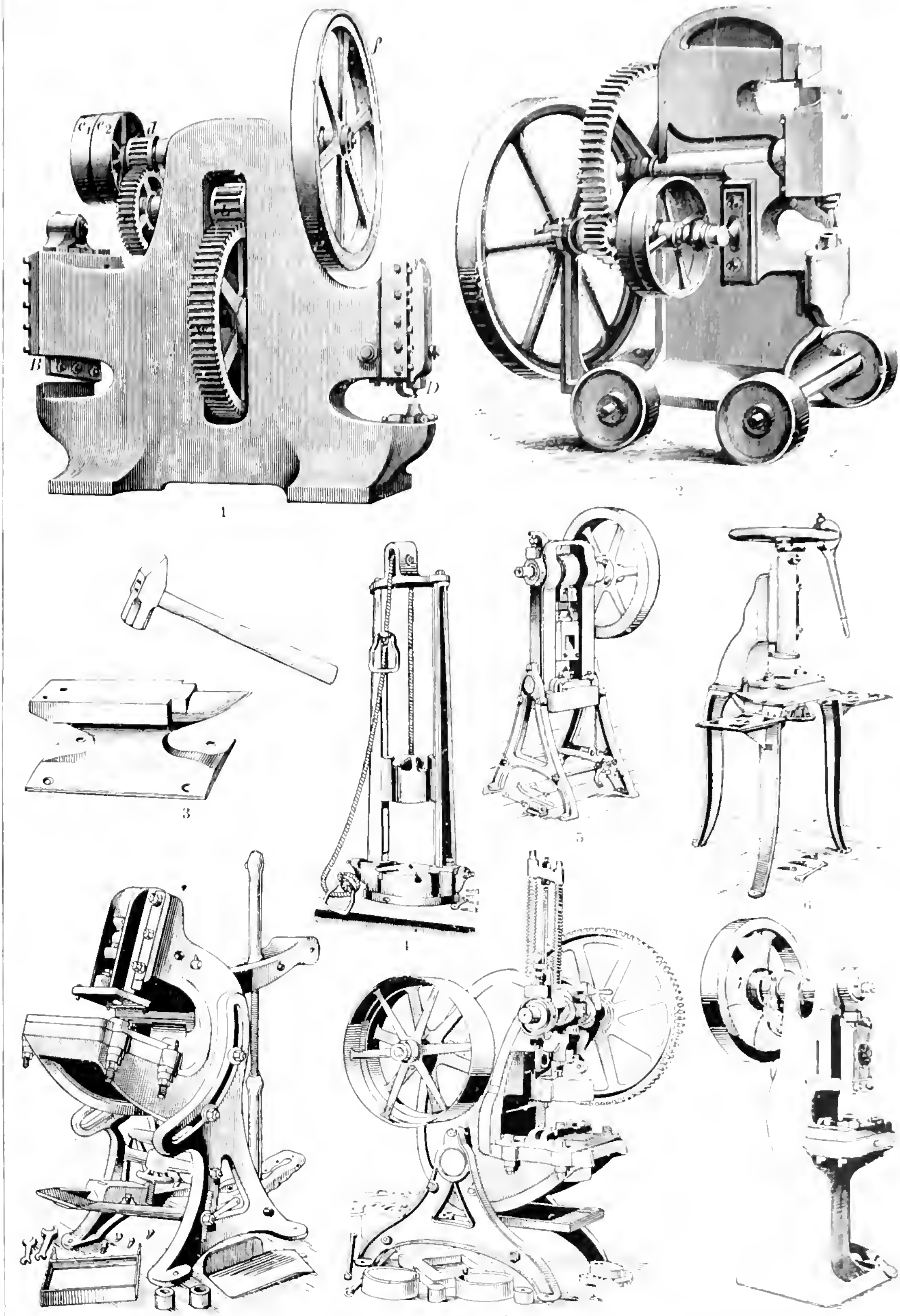
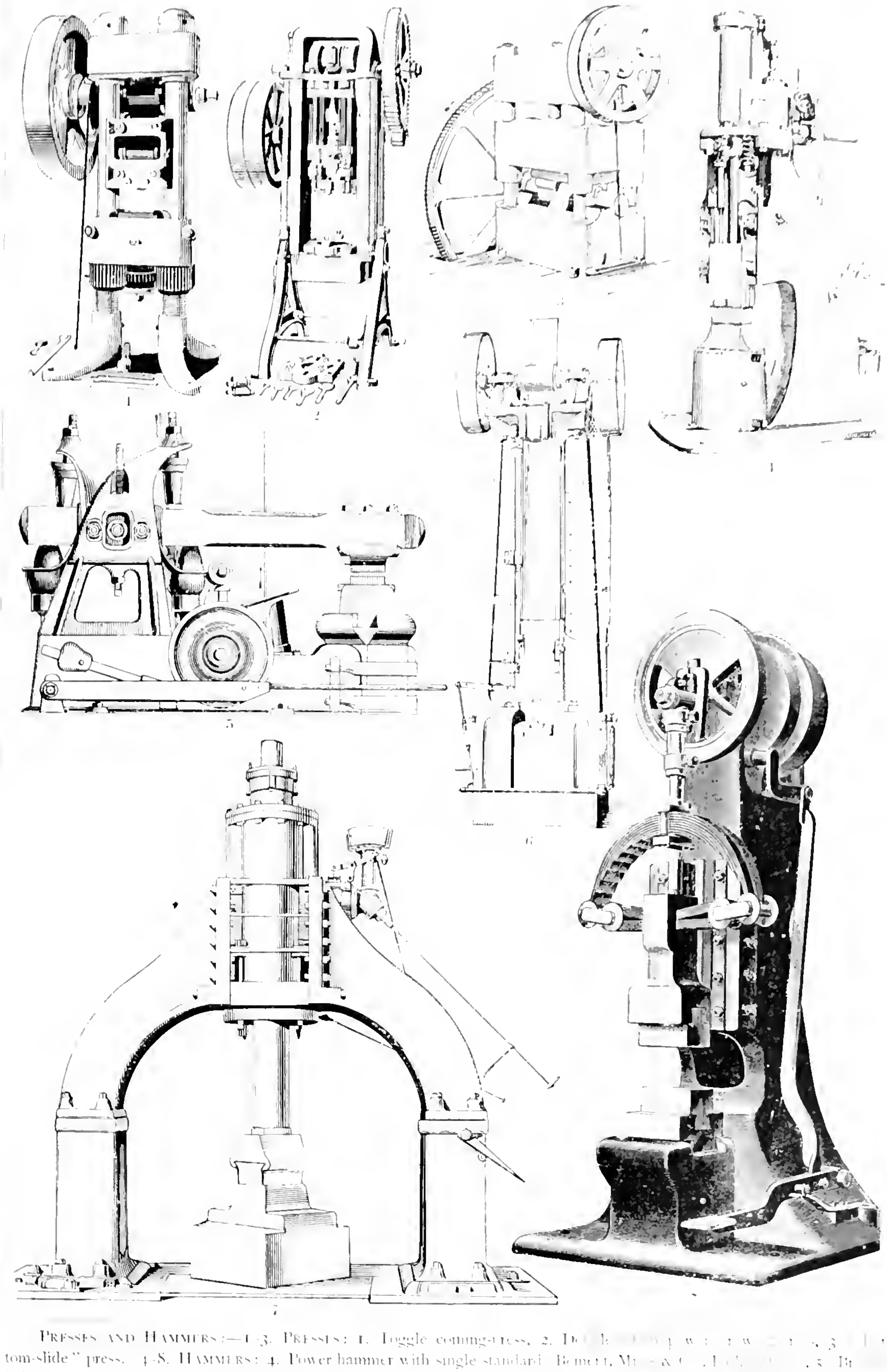


5

SHEARS AND PUNCHES: 1. Rotary or circular shear. 2. Duplex lever-shear. 3. D. B. [illegible] and punching machine. 4, 5. Parallel shears for boiler-plates.

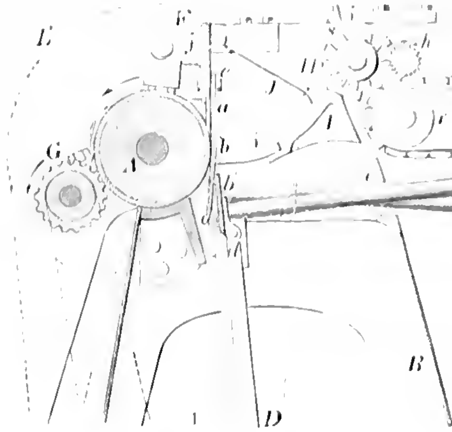


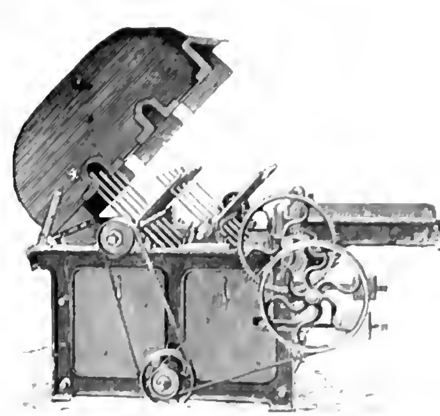
SHEARS, PUNCHES, AND PRESSES.—1. Parallel shears and punching machine. 2. [illegible] punching machine. 3–8. PRESSES: 3. Hammer and anvil. 4. Hand drop-press. 5. Power-press. 6. [illegible] draw-press. 7. Drawing-press. 8. Open-front draw-press. 9. Back-wheel punching press.



PRESSES AND HAMMERS:—1-3. PRESSES: 1. Toggle cutting-press, 2. D[illegible] press, 3. [illegible] tom-slide" press. 4-8. HAMMERS: 4. Power hammer with single standard (Bement, Miles & Co., [illegible]), 5. B[illegible] helve-hammer, 6. Drop-hammer (Pratt & Whitney Co., Hartford, Conn.), 7. Power hammer [illegible] (W. Sellers & Co., Philadelphia), 8. Shaw's crank-hammer

1. Penelope's web. 2. Egyptian women using the distaff. 3. Prehistoric flax [illegible] 4. Reel of the olden time. 5. Olden-time spinning wheel. 6. Mode of spinning [illegible] 7. [illegible] peasant's loom. 8. Mediæval hand-loom. 9. Hargreaves' spinning-jenny 1767. 10. [illegible] 1775. 11. Arkwright's spinning frame 1768.





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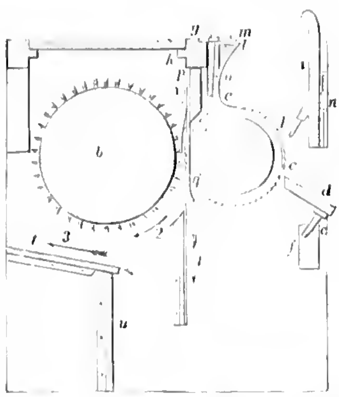

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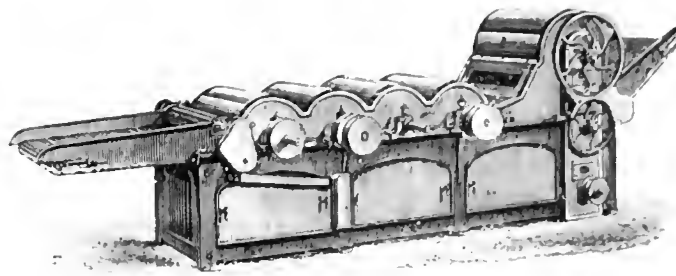

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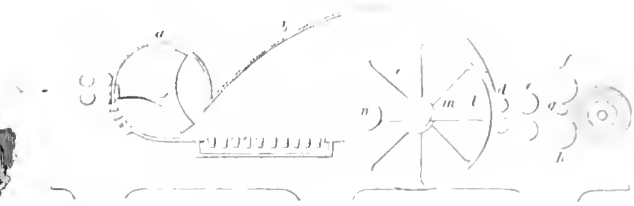

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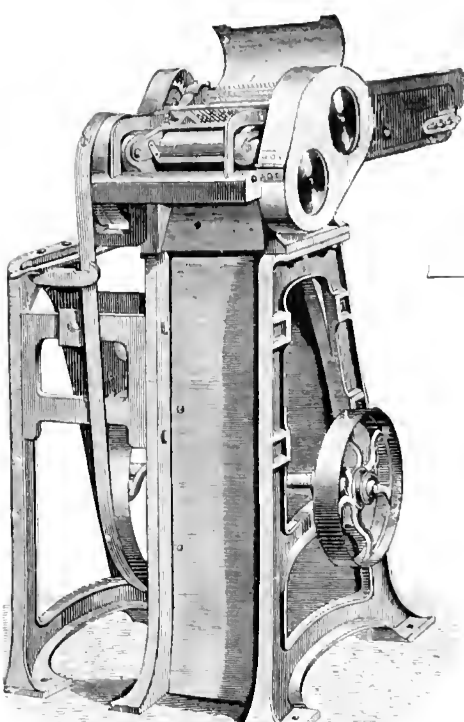

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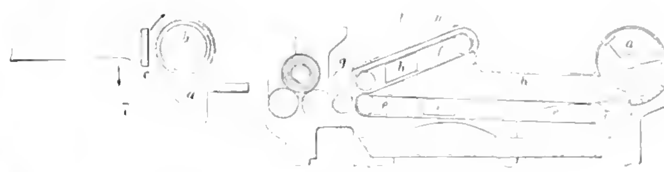
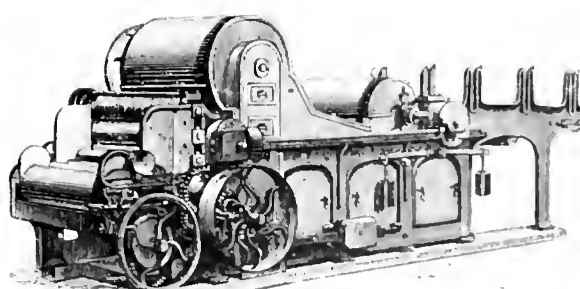
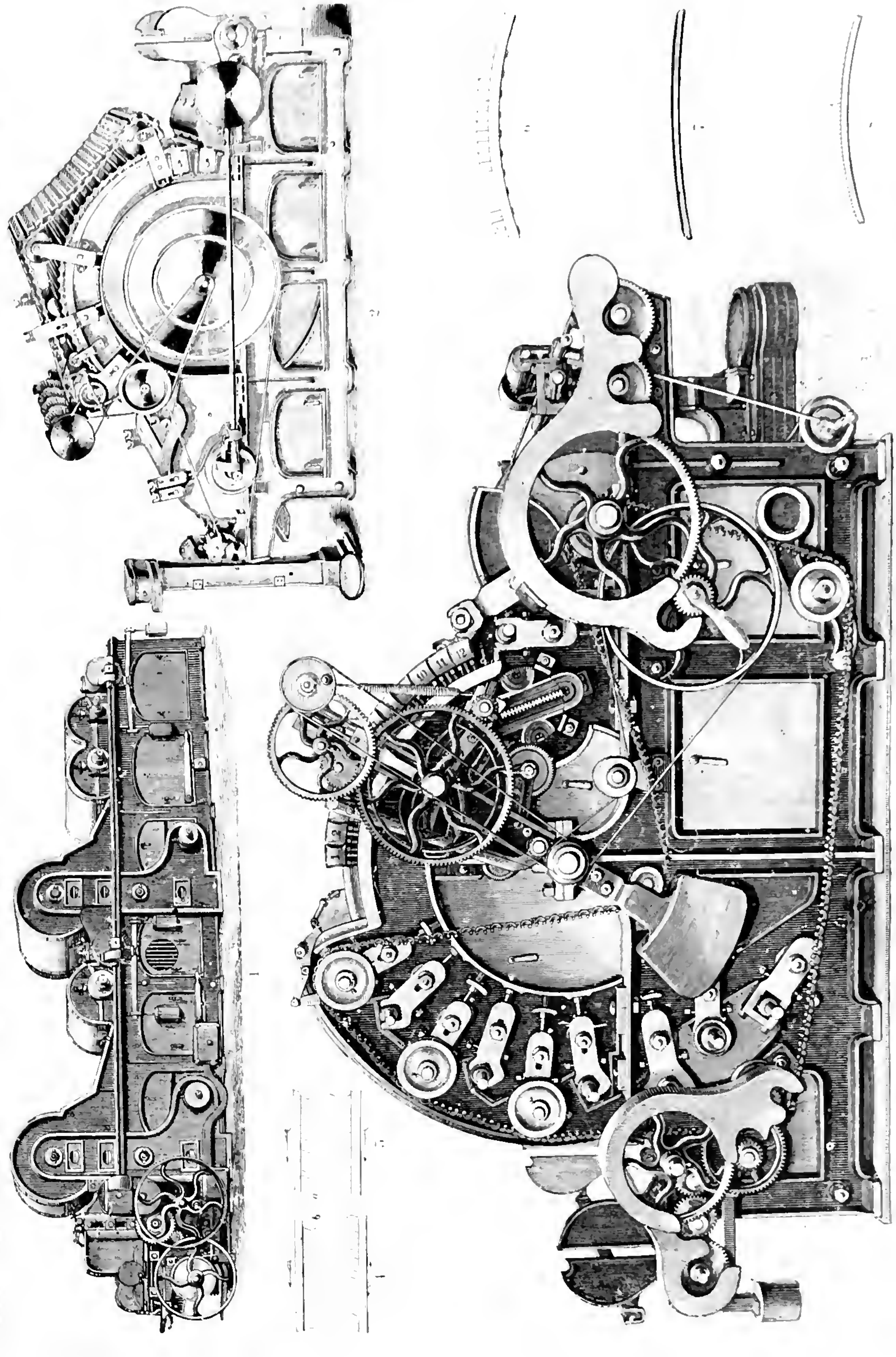
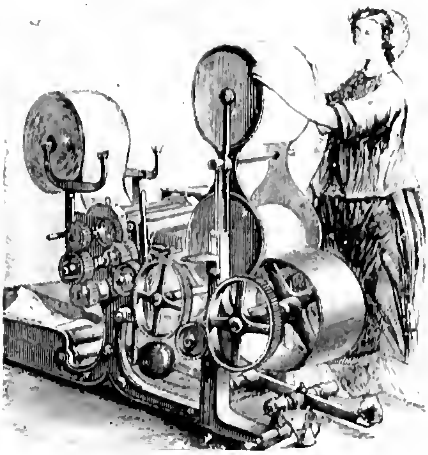




9

1. Comb-gin (vertical section of fig. 3). 2. Whitney saw-gin (1793). 3. C[illegible] gin [illegible]. 4. W[illegible] 5. Opener. 6, 8. Longitudinal sections of batting and lapping machines, illustrating [illegible] producing the lap. 7. Tray feeding for batting machine. 9. Combined [illegible]-scutcher and lapping machine.





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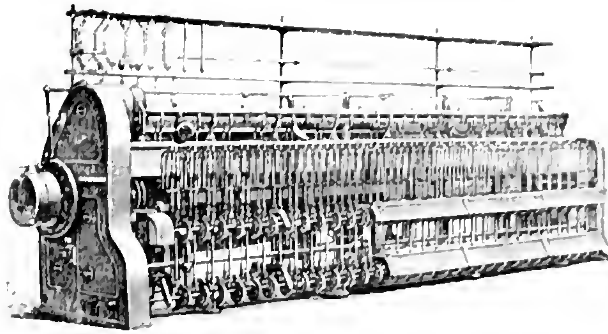

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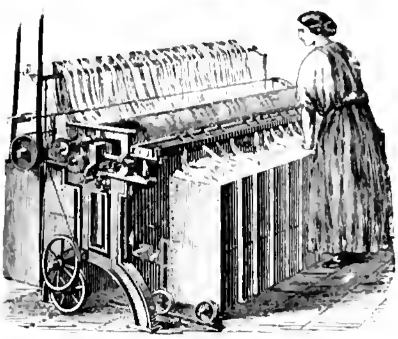

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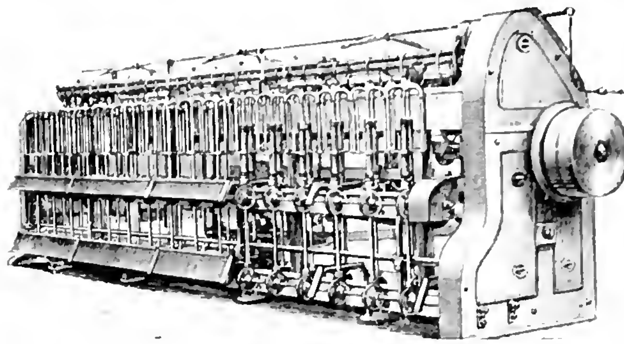

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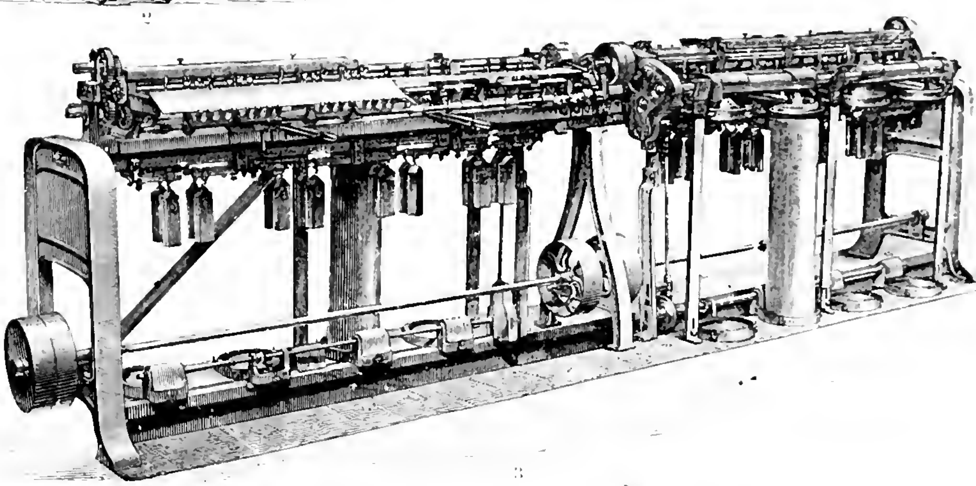

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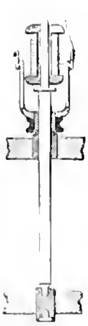

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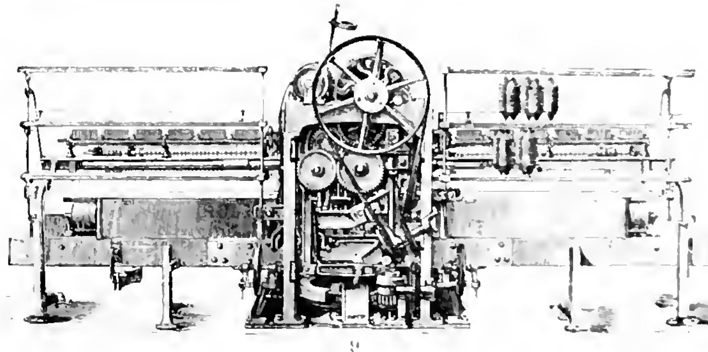
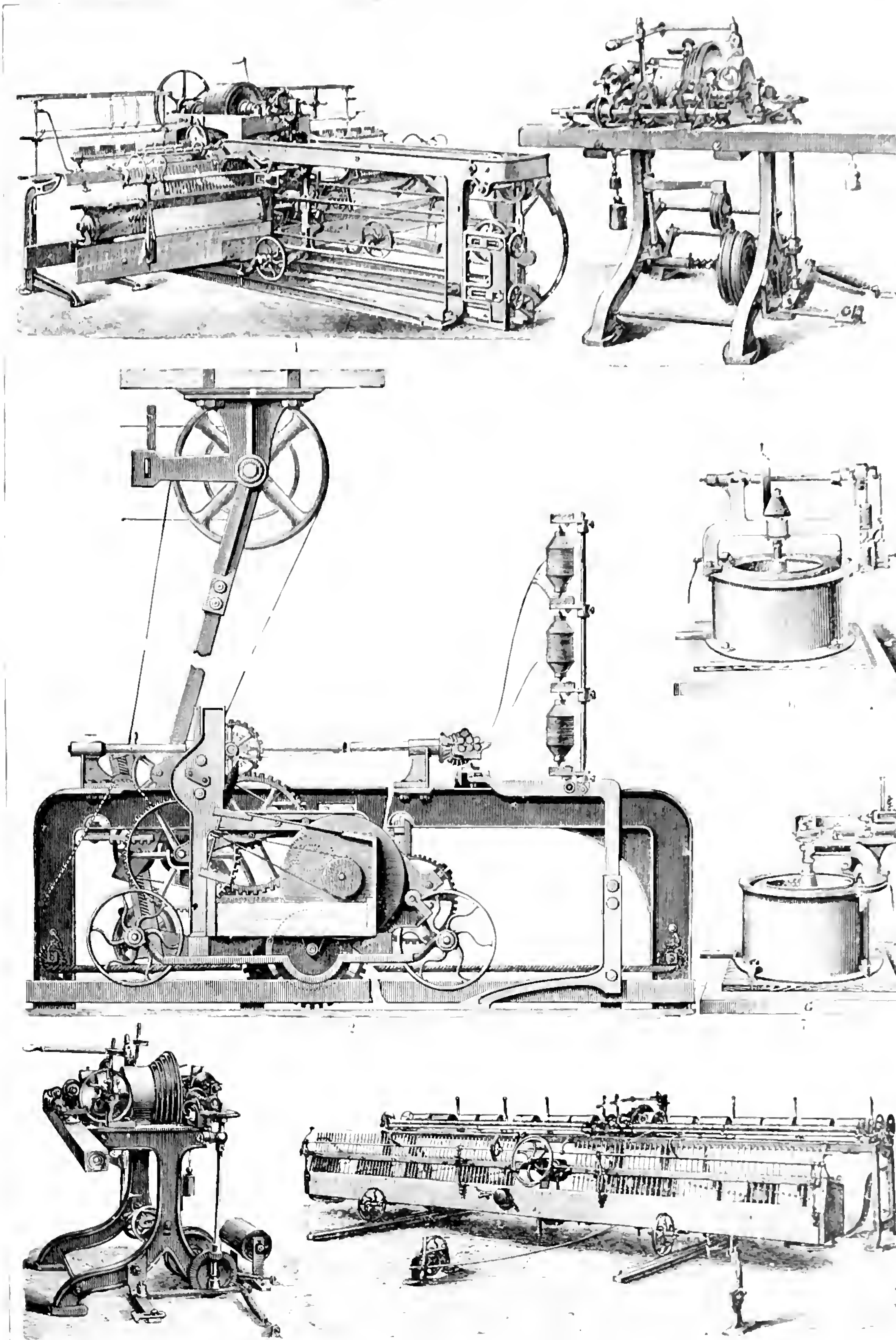
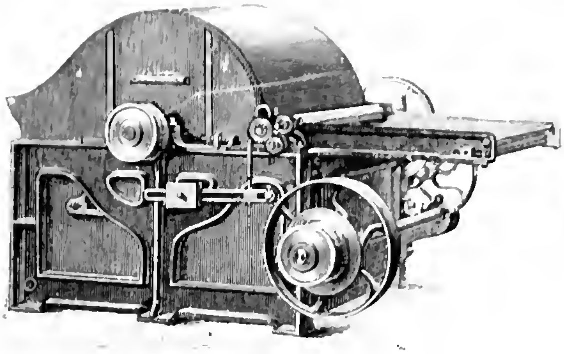


9

1. Canal drawing machine. 2. Temporary-twist roving machine. 3. Drawing [illegible] 4, 5 [illegible] twist roving. 6, 7. Fly throstles. 8. Section of "cop" produced by [illegible] 9. [illegible]



1, 2. Mules. 3. Front view, 4. Side view, of the head-stock of a self-acting m[illegible] 5. S[illegible] g woollen yarn. 6. Hydro-extractor operated by belt and friction cones. 7. Hy[illegible] s steam-engine.



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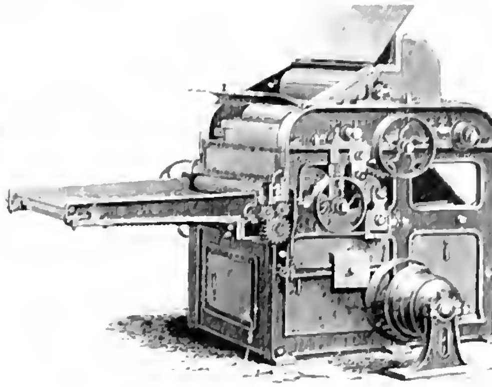

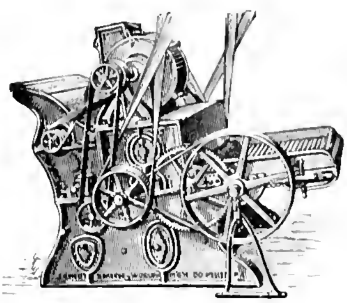

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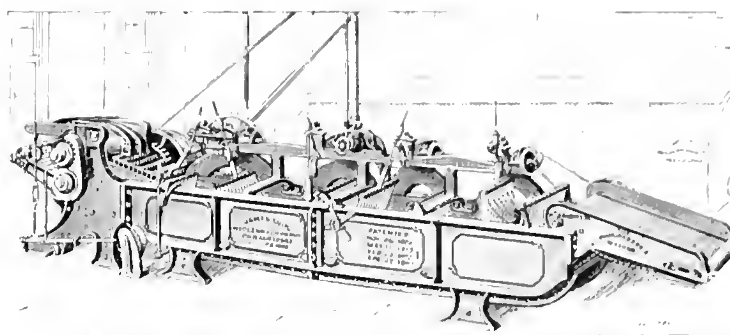

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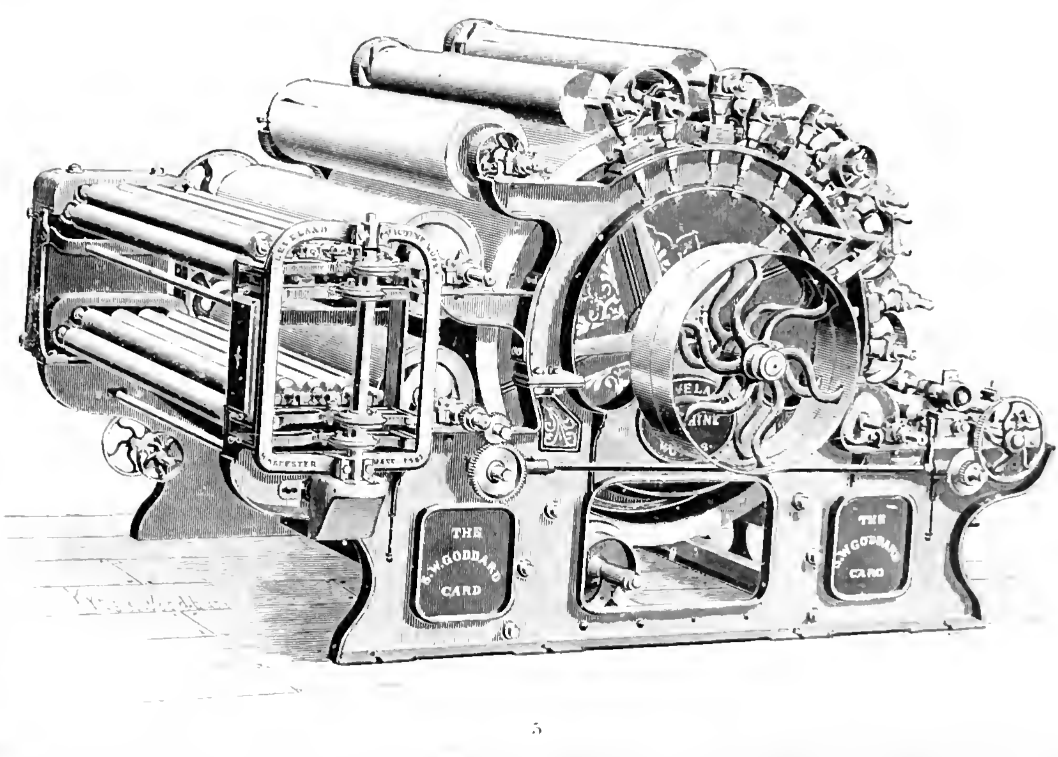
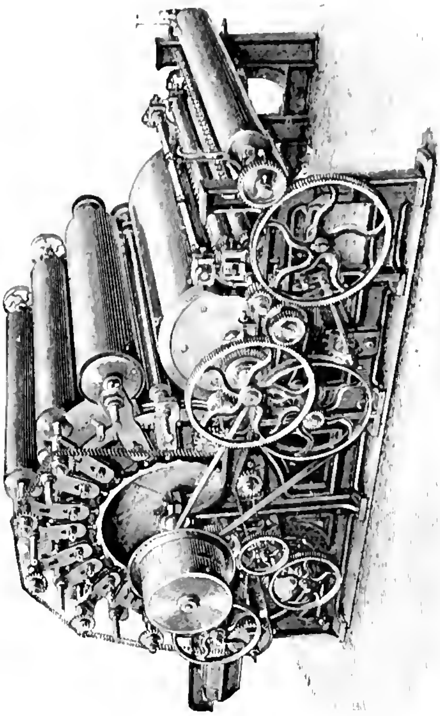
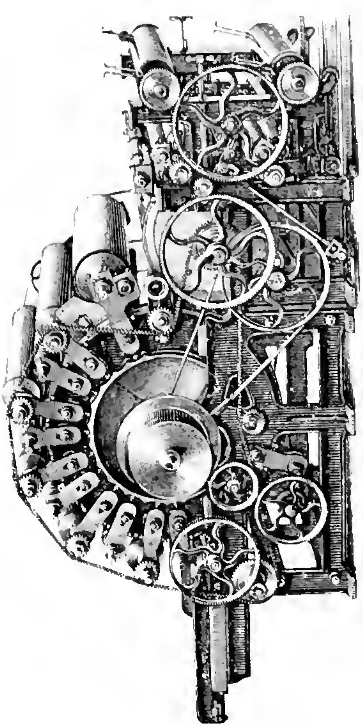
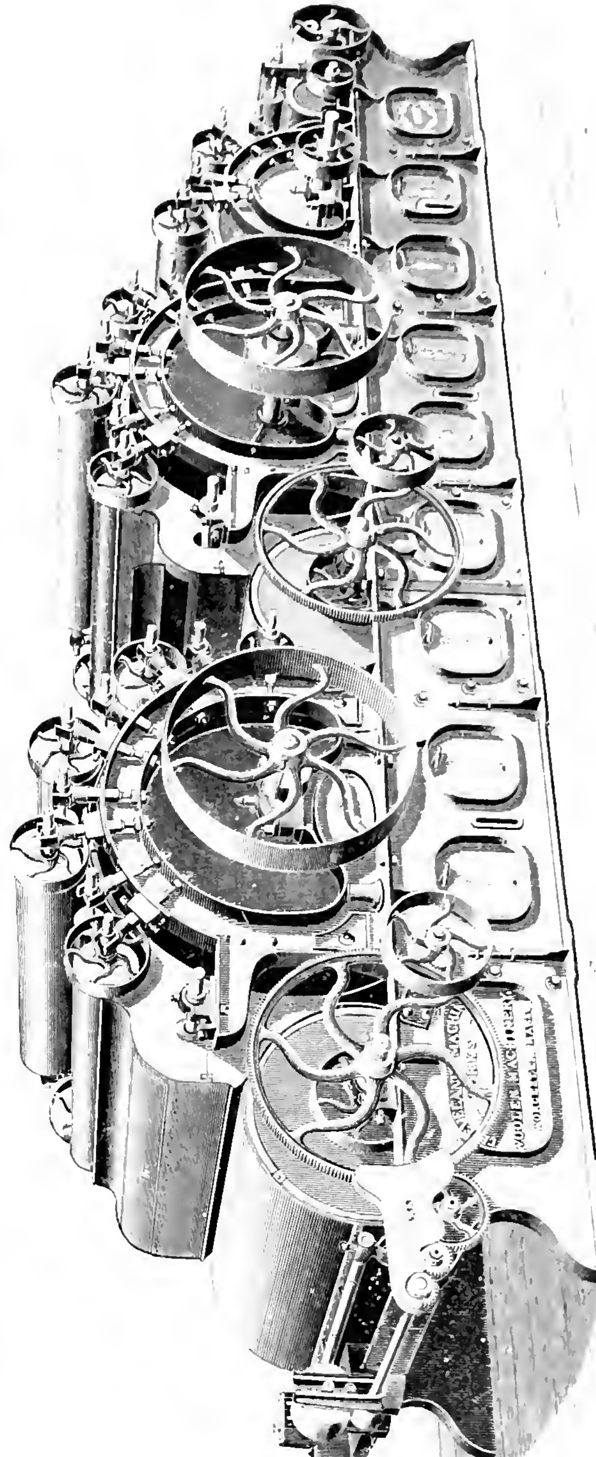


5

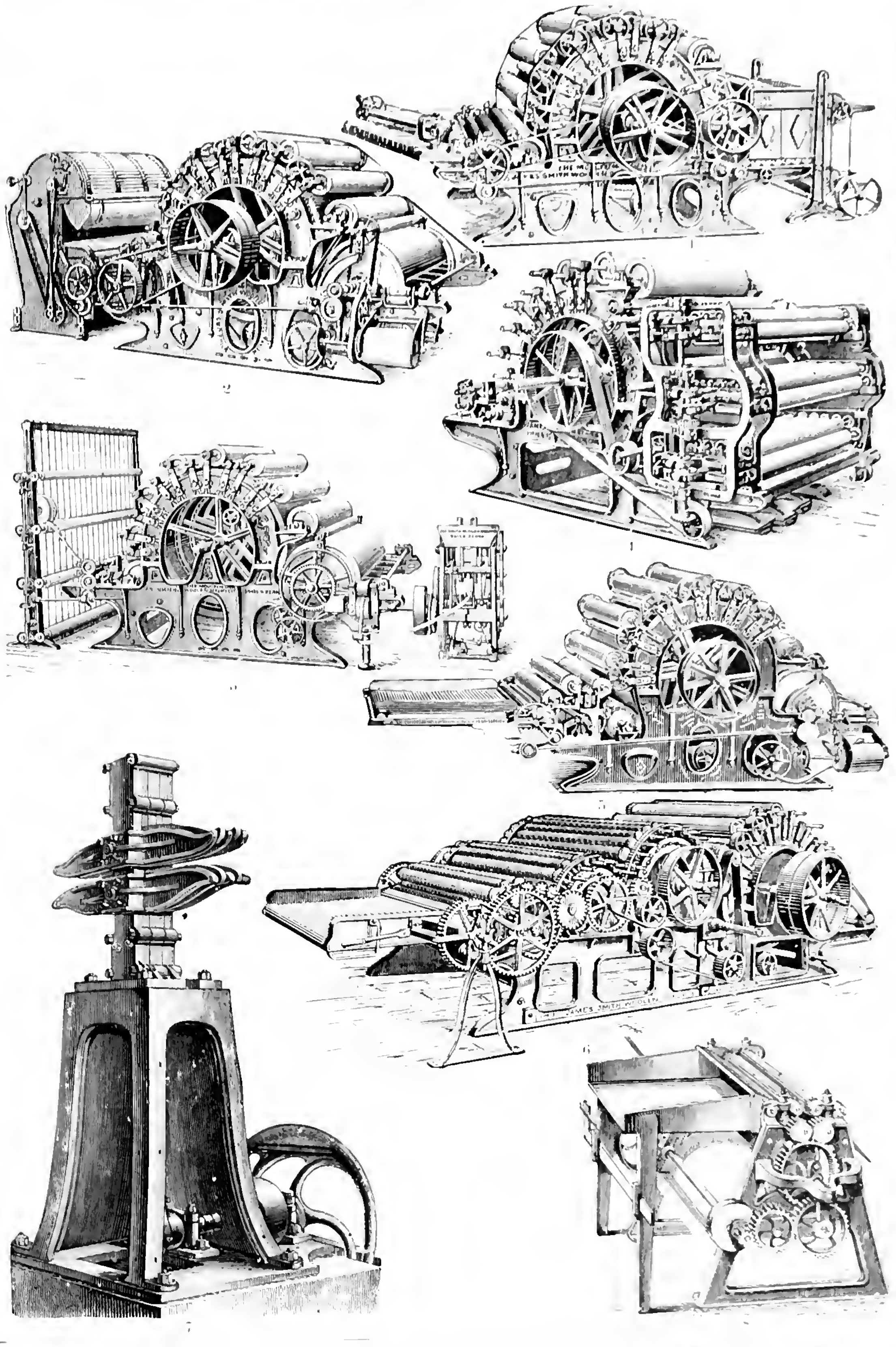
1. Wool-picker or opening-machine. 2, 3 W[illegible] ing m[illegible] 4 W[illegible] w[illegible] S. W[illegible] Machine Co., Philadelphia. 5 Finisher-card of an American [illegible] Mass.



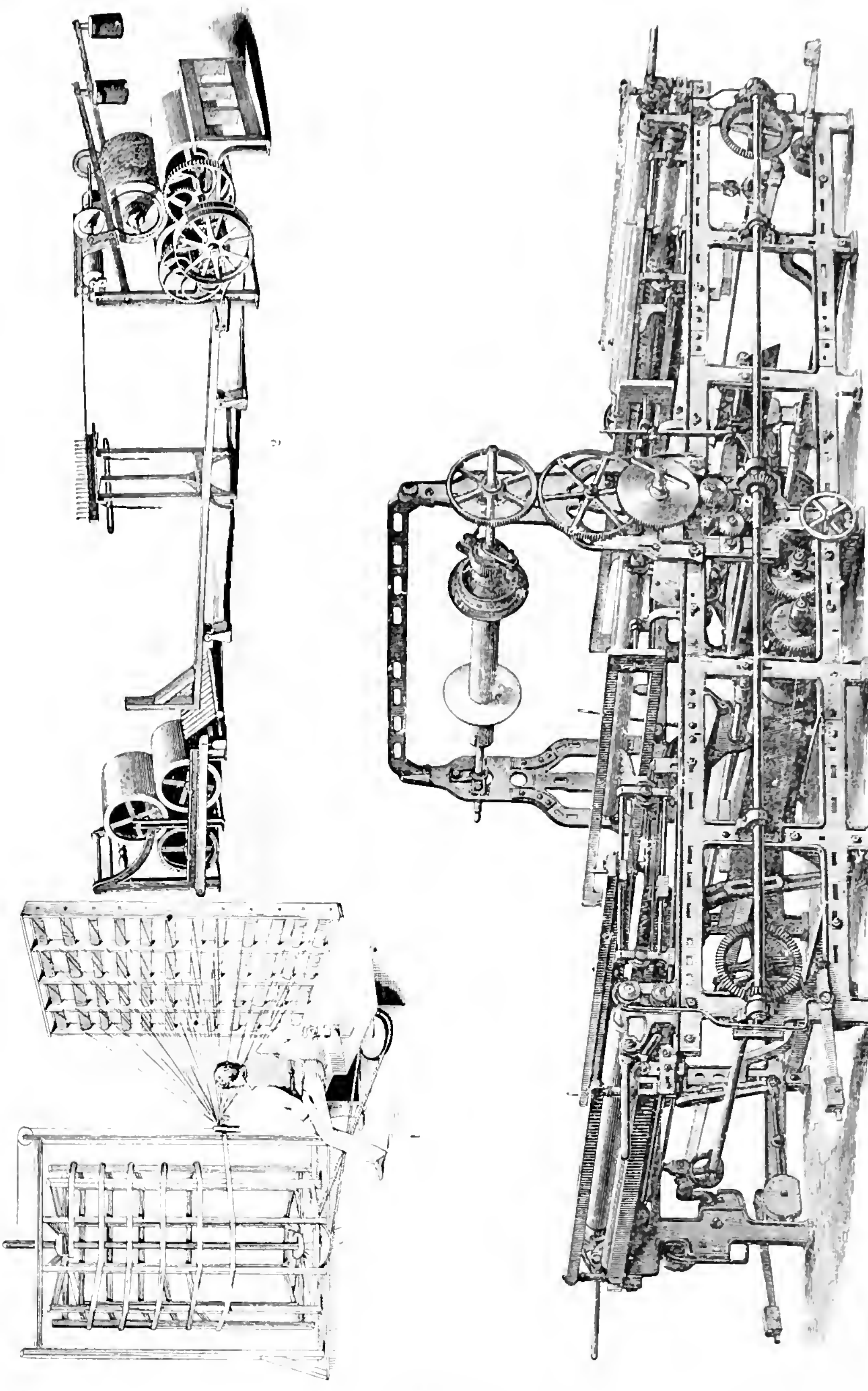




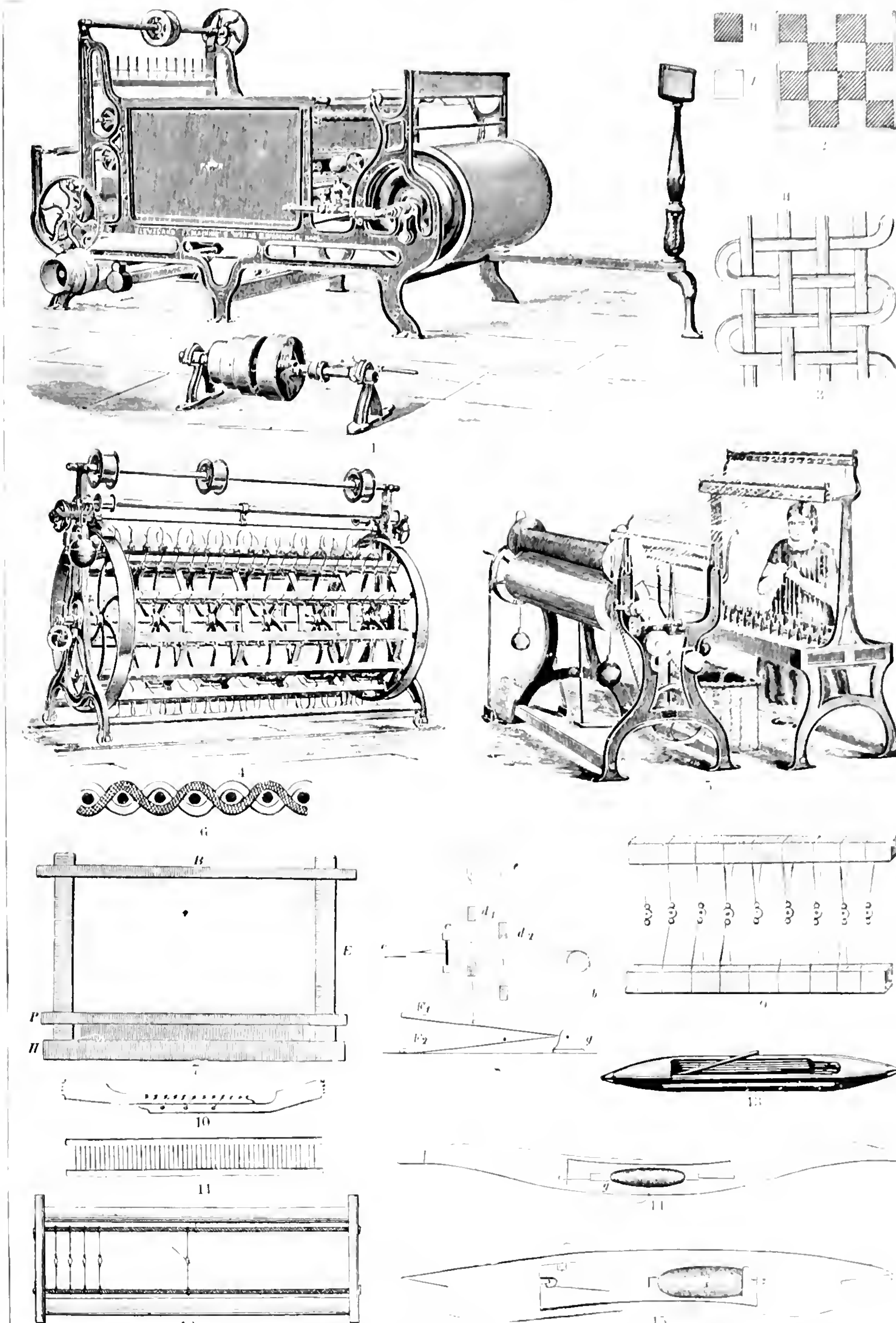
1. Double [illegible] 2. Single [illegible] 3. Double cylinder worsted card with [illegible]



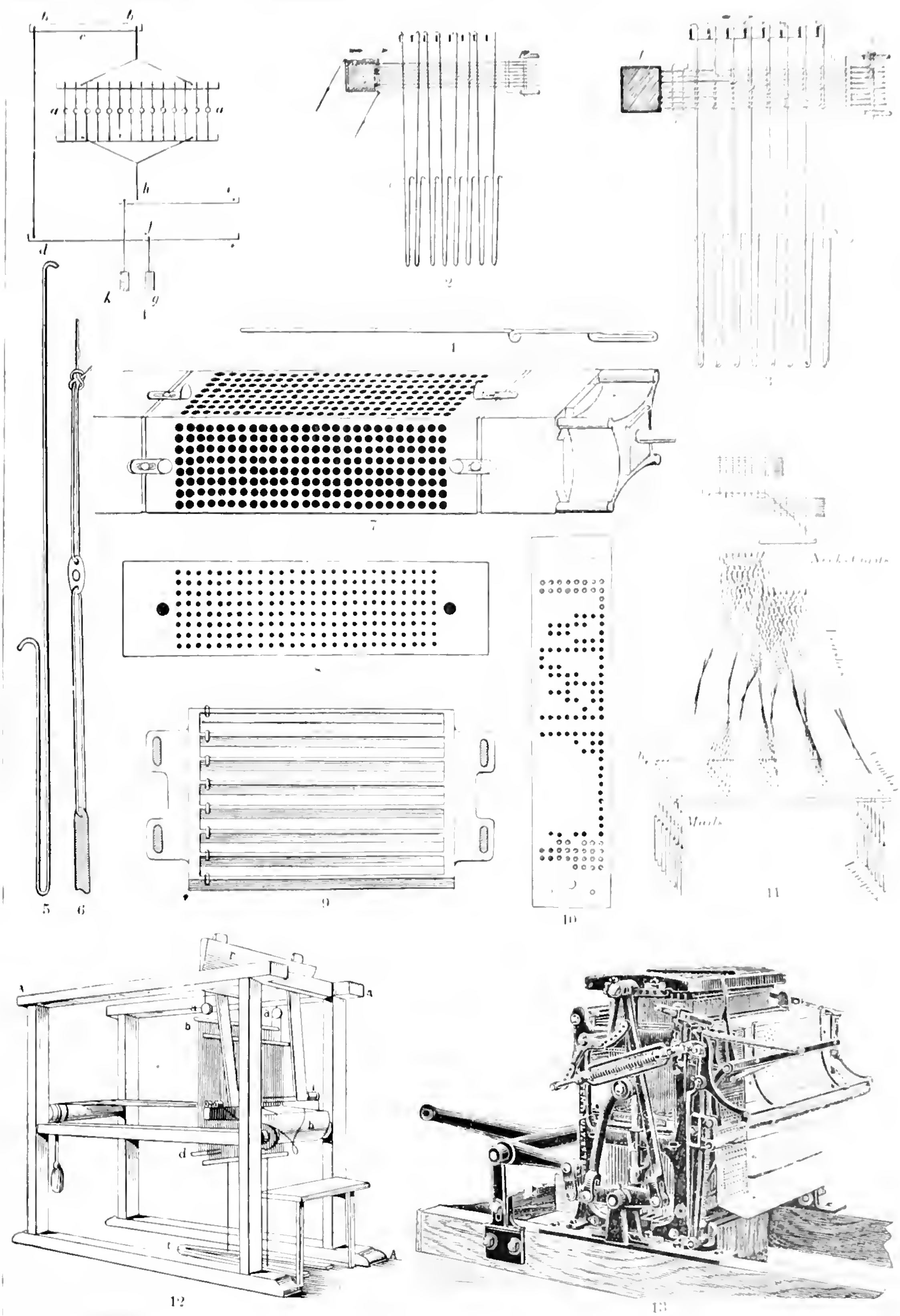
1. Finisher card with Apperly feed, 2. First breaker-card with Bramwell feed, 3. S[illegible] and balling-head, 4. Three-doffer finisher card, 5. First breaker card with [illegible] card (James Smith Woolen Machine Co., Philadelphia). 7. Lever flax-breaker. 8. [illegible] teaser



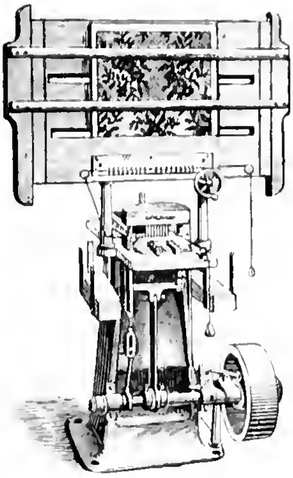
1. Chain warping machine. 2. Beaming machine. 3. Warping machine for cotton.



1. Yarn sizing-dresser (Cleveland Machine Works, Worcester, Mass.). 2. Plan of [illegible]. 3. [illegible] with plain weave (*fig.* 2). 4. Section-reel (Cleveland Machine Works). 5. Yarn-spooler [illegible] M[illegible] Works). 6. Cross-section of plain weave. 7. Batten of a hand loom. 8. Arrangement of harness [illegible]. 9. Harness-frame and twine heddles. 10. Temple. 11. Reed. 12. Harness-shaft with wire [illegible]. 13. [illegible] shuttle for weaving cloth. 14, 15. Shuttles for hand looms.



1–11. Details of the Jacquard machine: 1. "Comper," 2, 3. Action of needles and hooks, 4. N[illegible], 5. Hook, 6. Lingo, 7. Cylinder, 8. Needle-board, 9. Griffe, 10. Card, and 11. Tie-up of harness. 12. Harness [illegible]. 13. Double-lift double-cylinder Jacquard machine.



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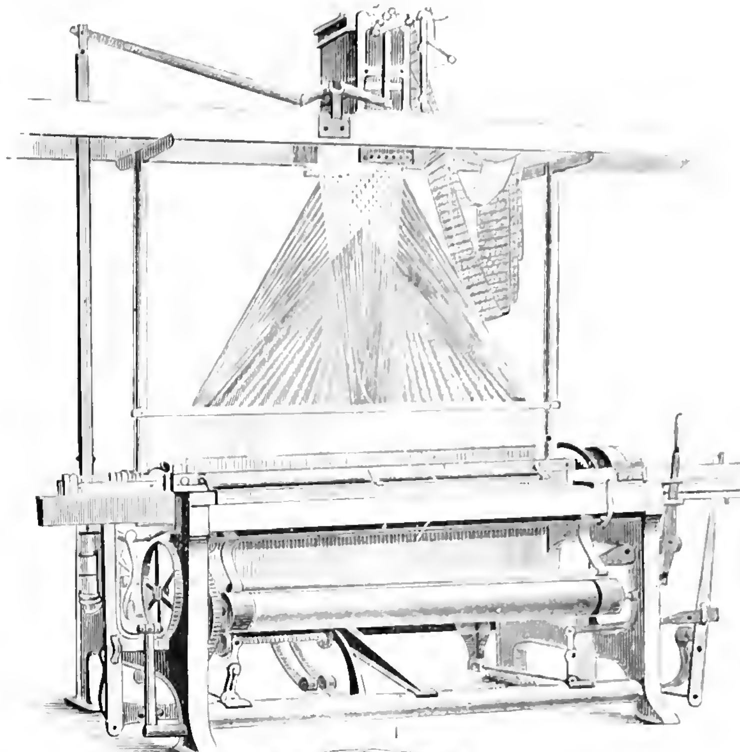

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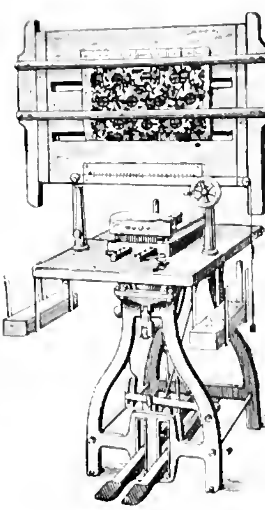

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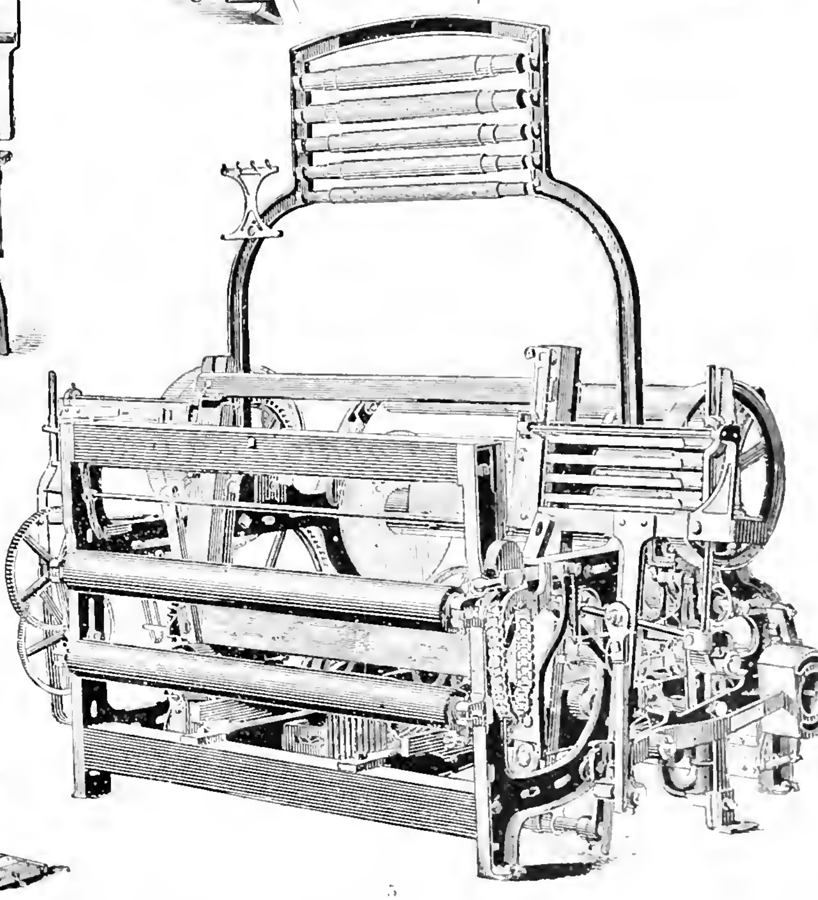
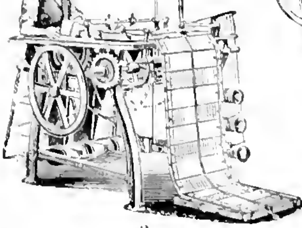
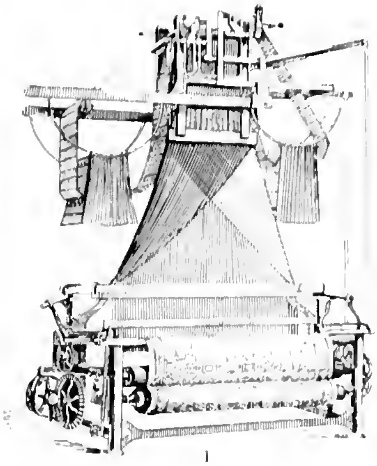




3

5

1 Piano steam-power card-stamping machine. 2 Piano foot-power card-stam[illegible] 3 [illegible] machine. 4 Single-lift Jacquard machine adjusted to a loom (Schaum & Uhlinger, [illegible]). 5 [illegible] Br[illegible]burg Manufacturing Co., Philadelphia.



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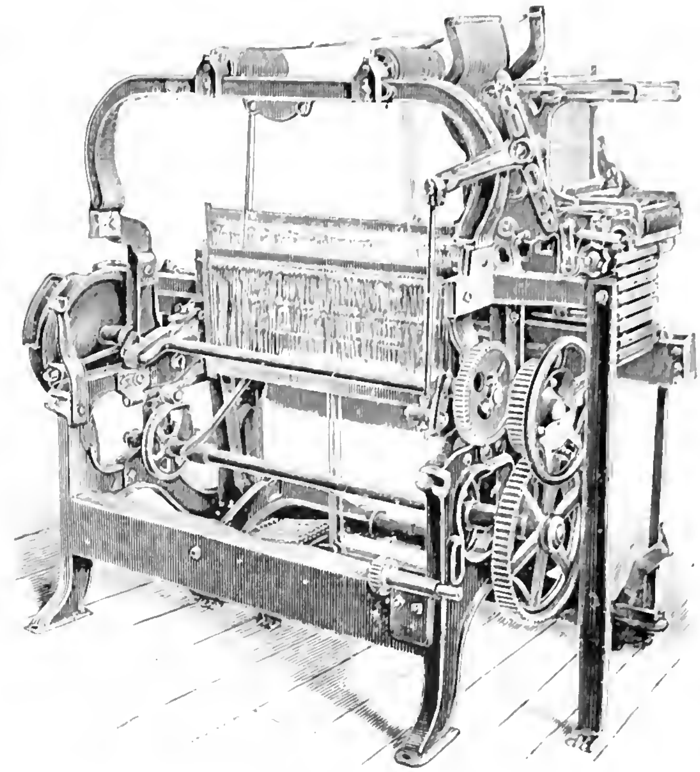

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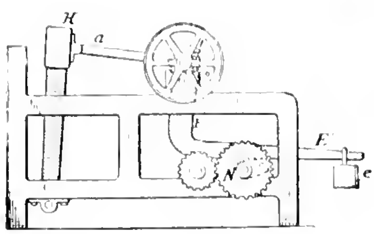

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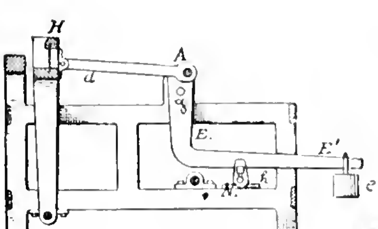

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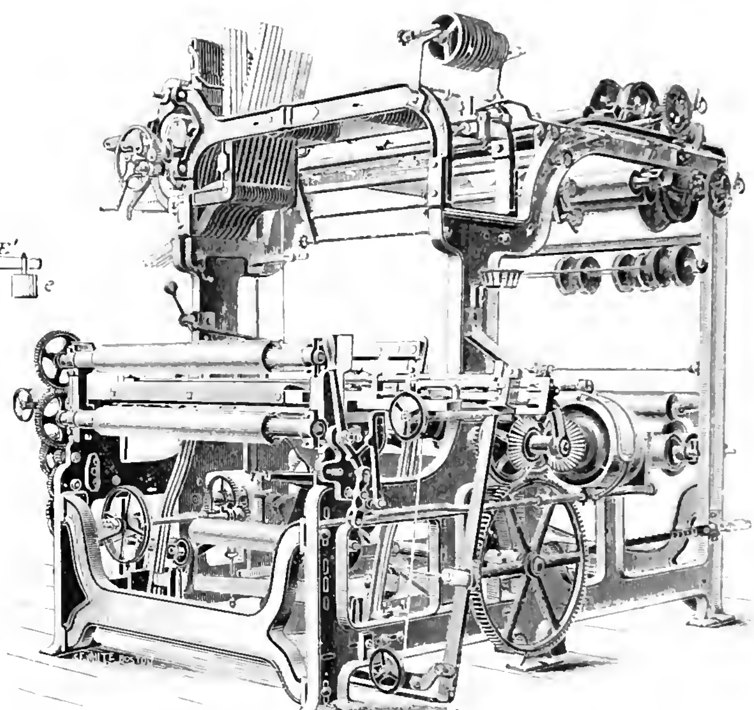

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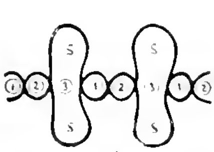
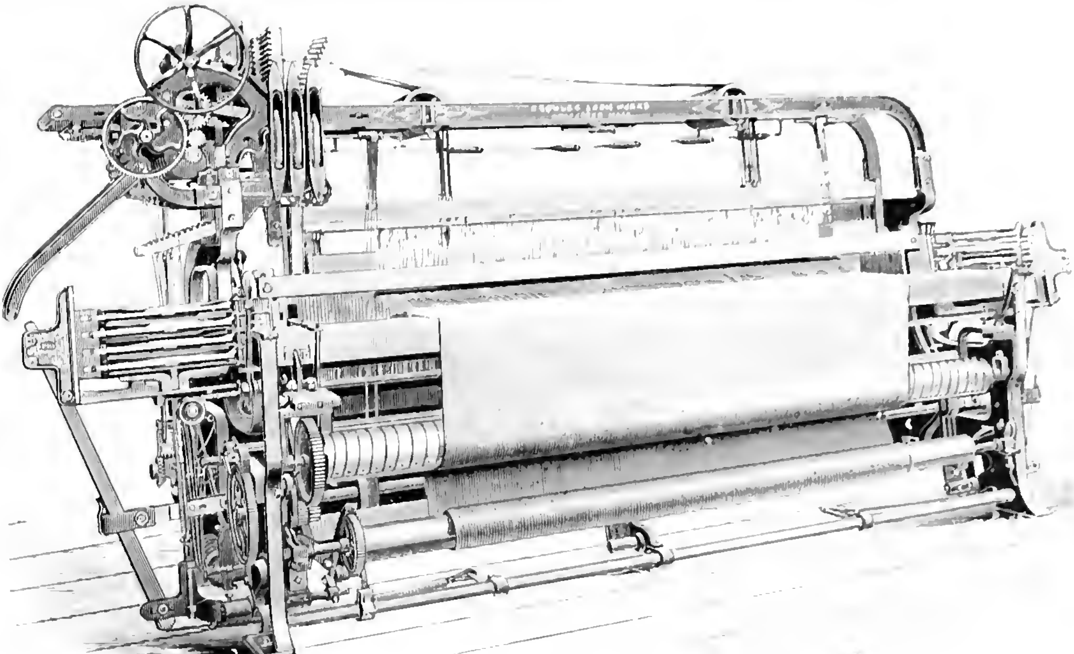


4

5

1. Double-lift, double-cylinder Jacquard machine attached to loom. 2, 3. Terry [illegible] 4, 5. [illegible] terry w[illegible] on looms in Figures 2 and 3. 6. Positive double-acting dobbie (George W. Stafford & C[illegible], [illegible], R. I.). 7. D[illegible] shuttle plush-loom (Knowles Loom Works, Worcester, Mass.



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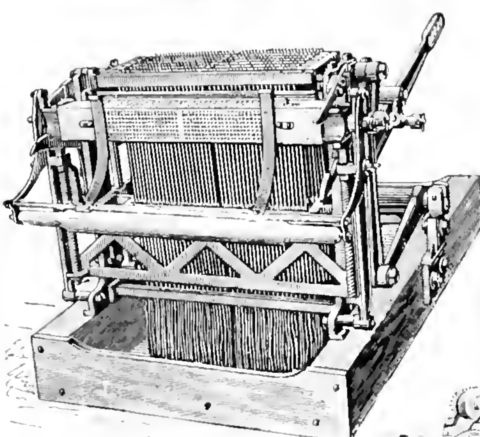

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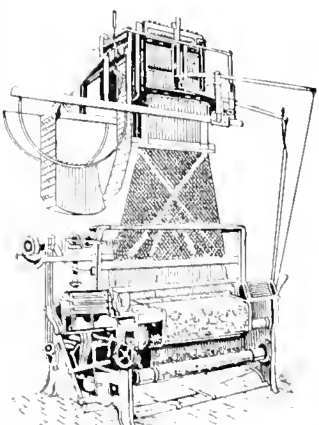

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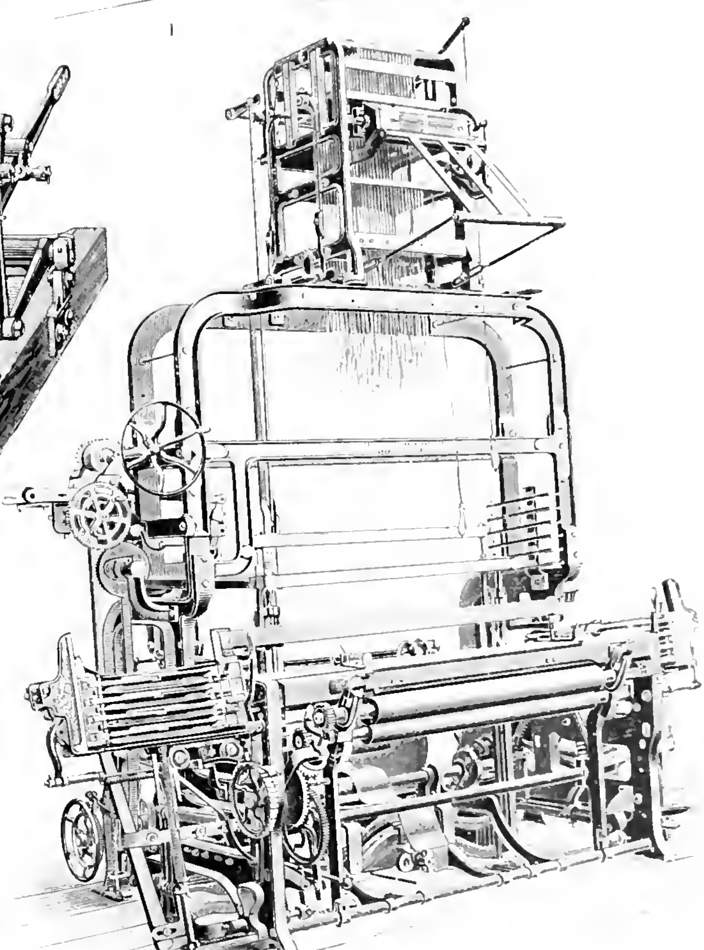
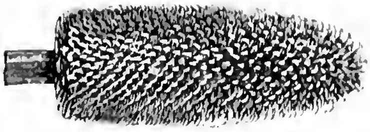


4

1. Heavy worsted- and woollen-loom (Knowles Loom Works, Worcester, Mass.). 2. [illegible] (Schaum & Uhlinger, Philadelphia). 3. Double-lift, single cylinder Jacquard machine attached [illegible] 4. Ingrain-carpet power-loom (Knowles Loom Works).



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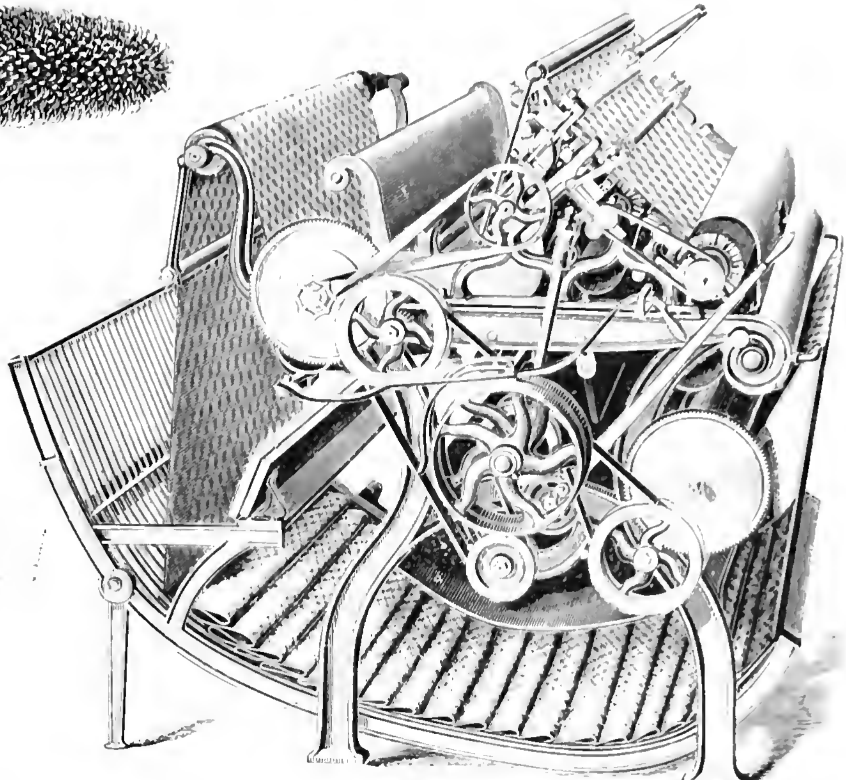

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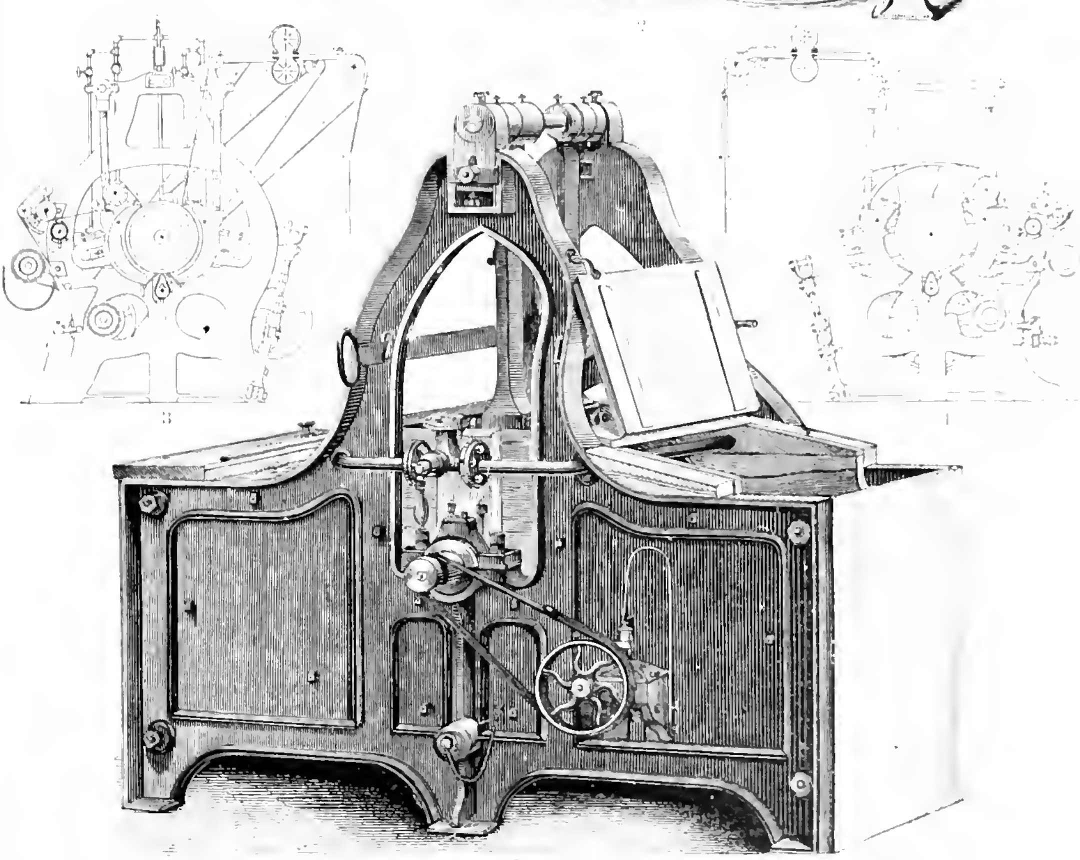
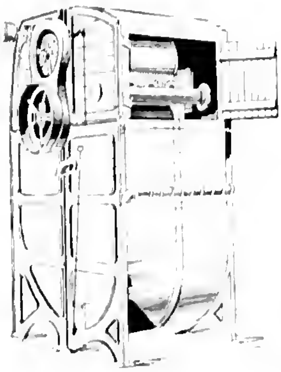


3 4 5

1. Teasel. 2. Improved shearing machine (Parks & Woolson Ma[illegible], Springfield, Vt.) 3, 4. [illegible] cloth-press (David Gessner, Worcester, Mass.) 5. German fulling-mill.



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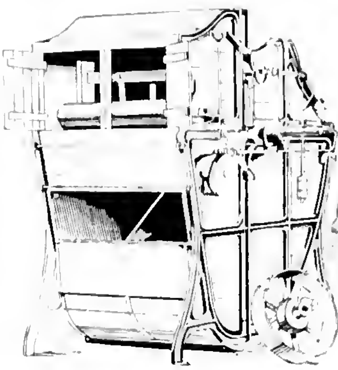

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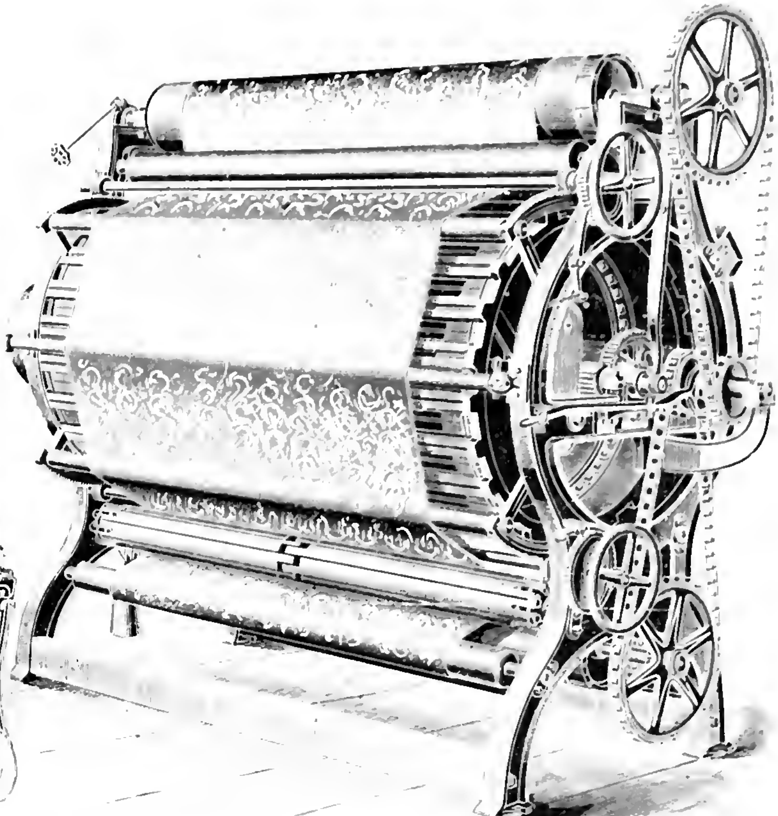

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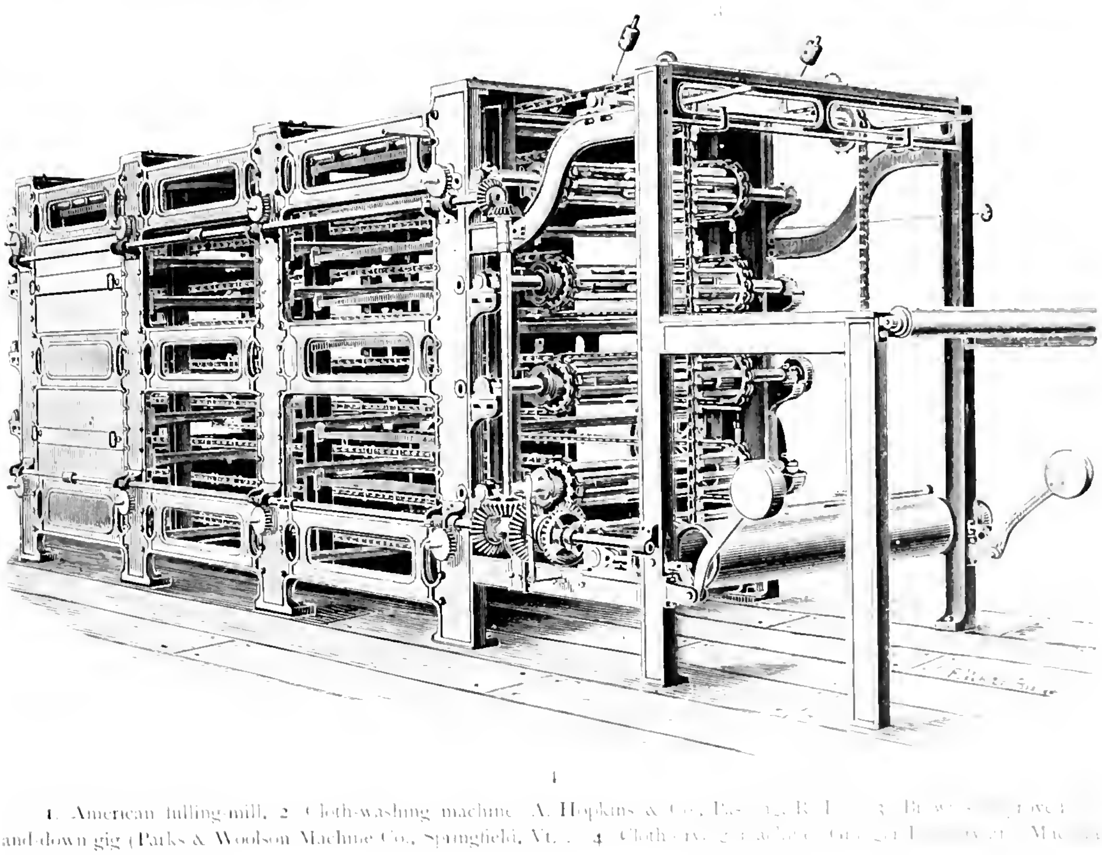
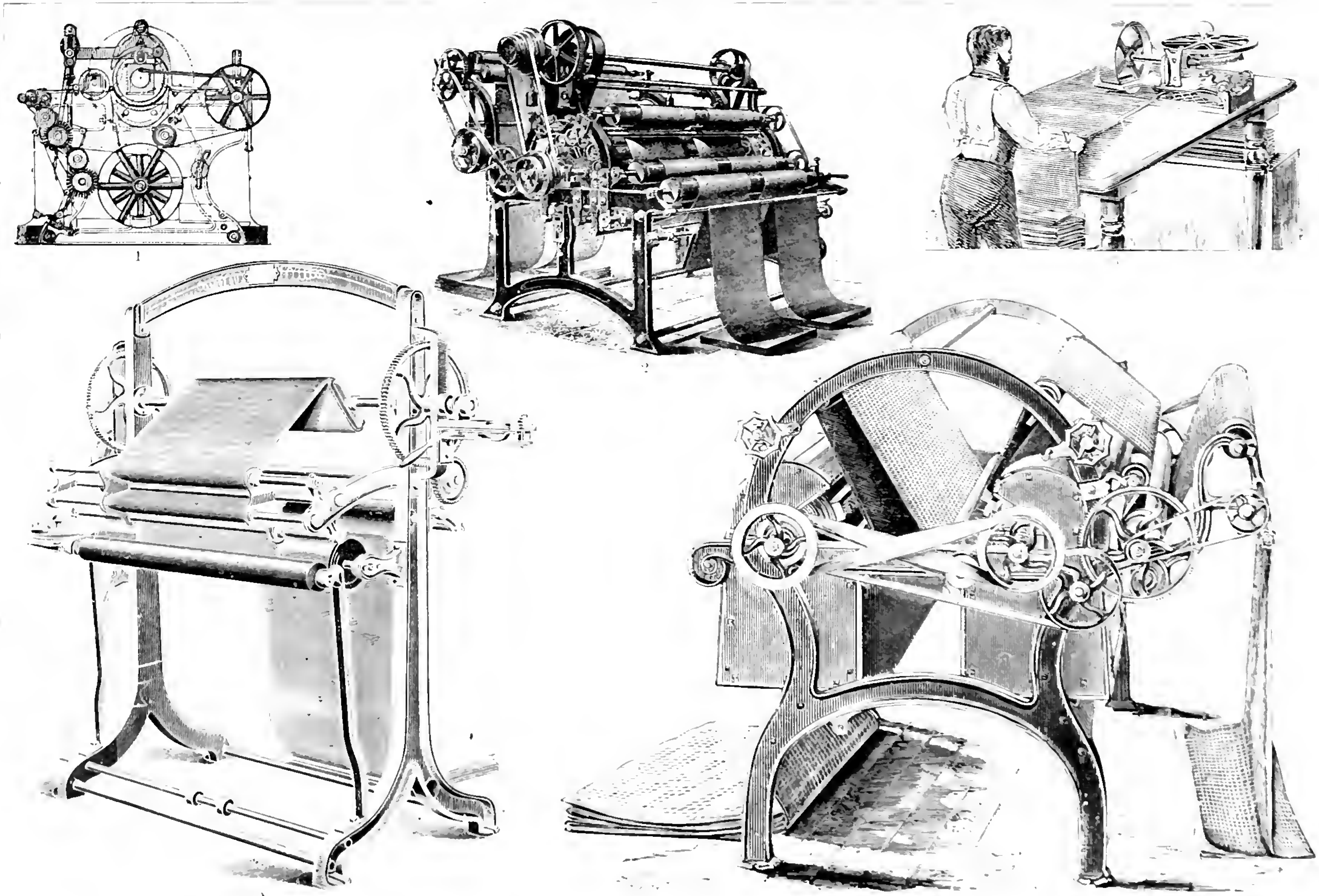
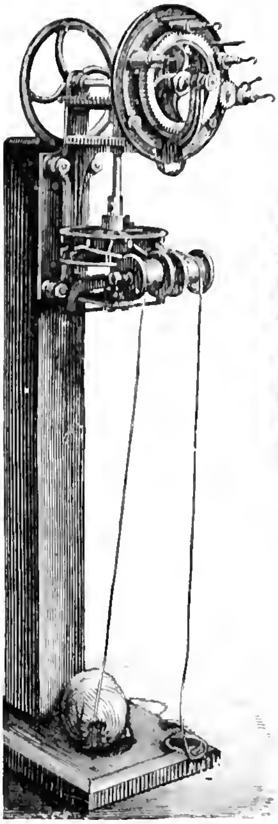


4

1. American fulling-mill. 2. Cloth-washing machine (A. Hopkins & Co., Pas[illegible], R. I.). 3. Br[illegible] and-down gig (Parks & Woolson Machine Co., Springfield, Vt.). 4. Cloth-[illegible] Ma[illegible] Co., Providence, R. I.).



1. Mill [illegible] steam cylinder rotary cloth press, (Woonsocket (R. I.) Machine & Press Co.) 2. K[illegible] Charles H[illegible] [illegible] 4. Brown [illegible] cotton measuring and winding machine. Parks & Woolson Machine Co., Springfield, Vt. 5. Brushing machine [illegible]



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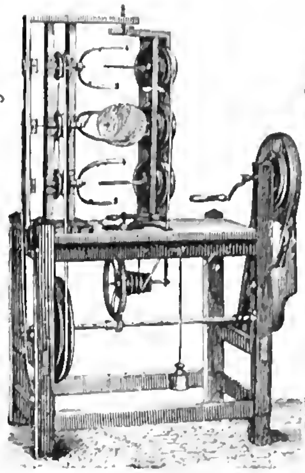

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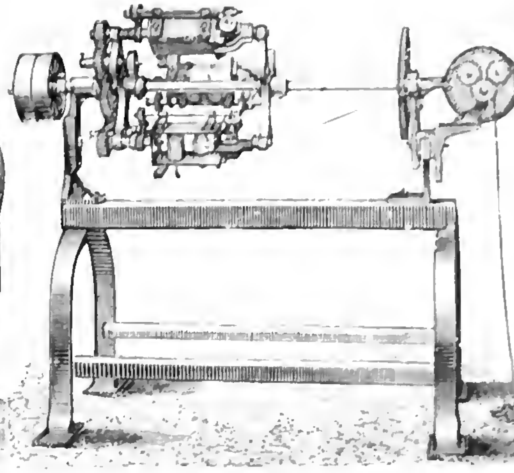

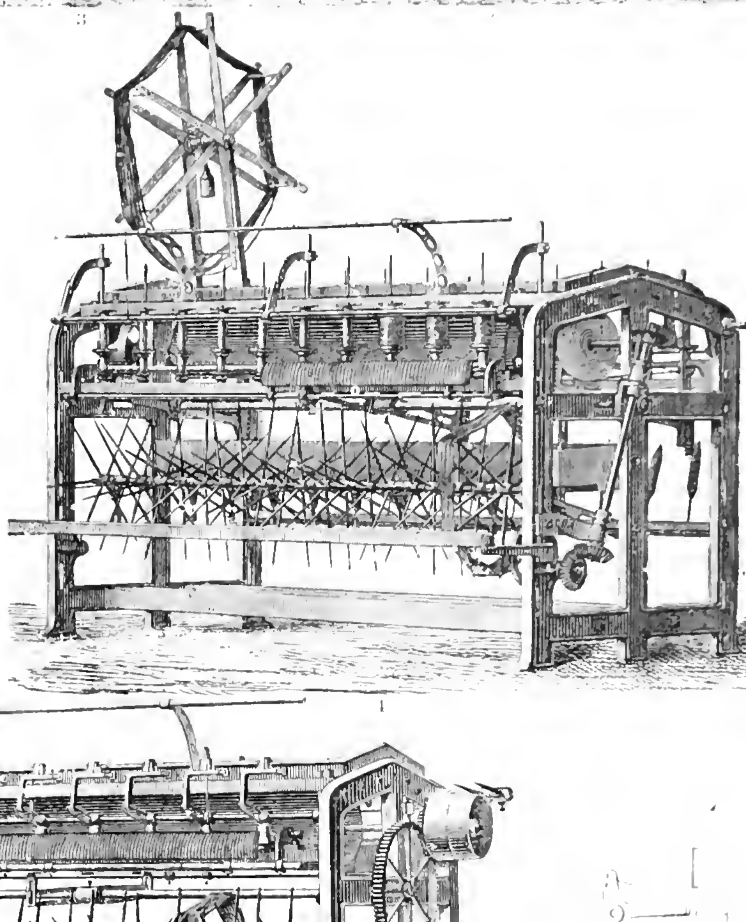

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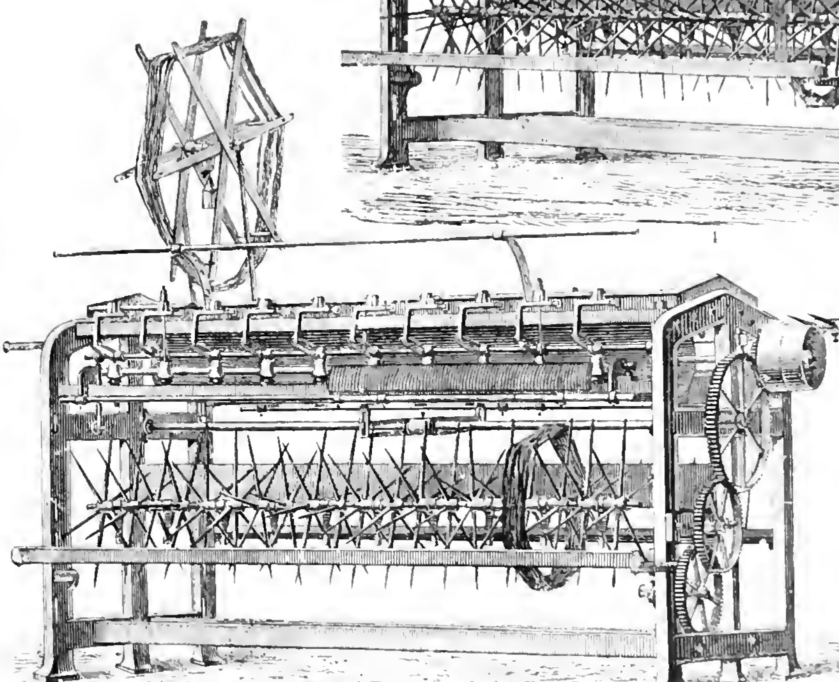

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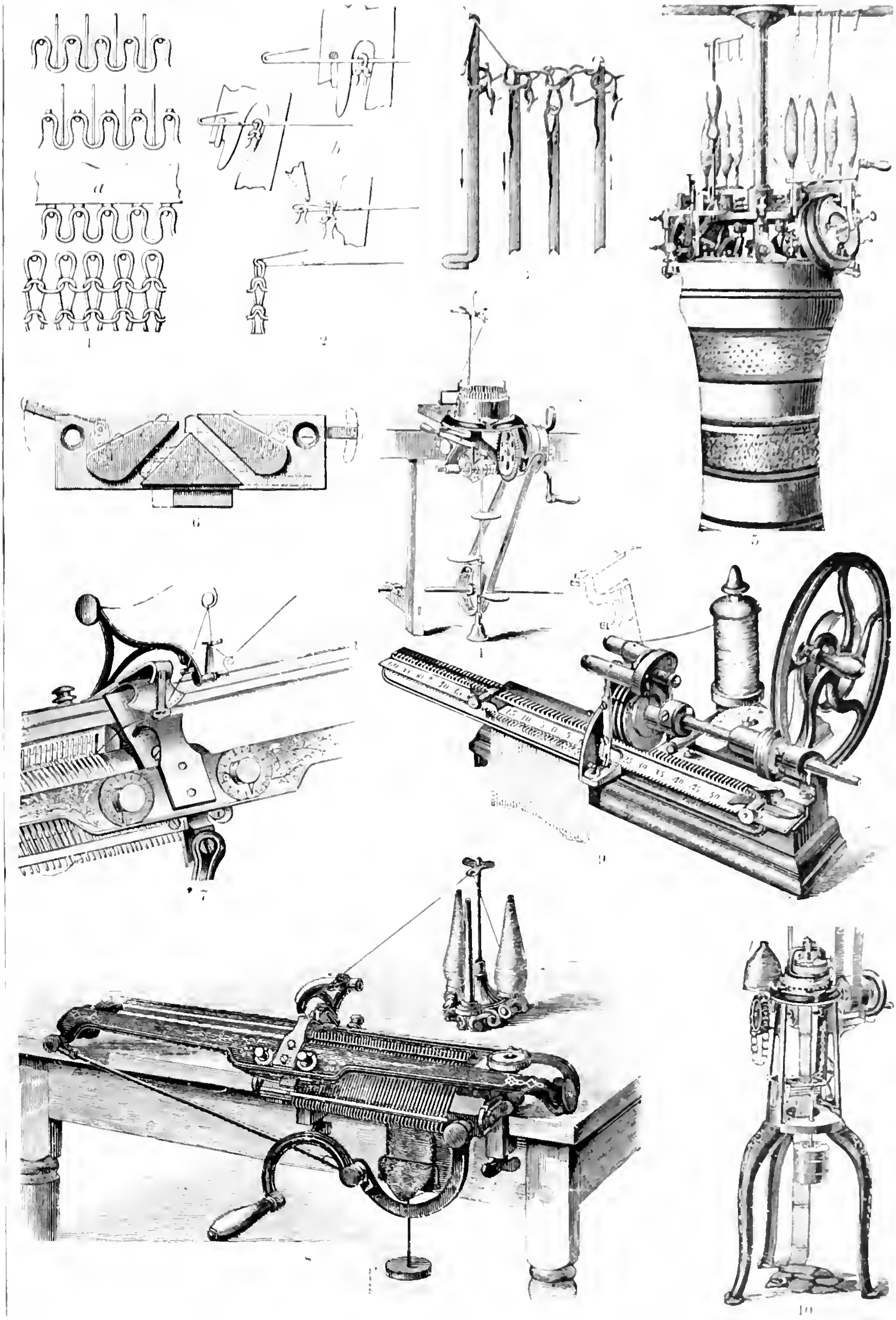
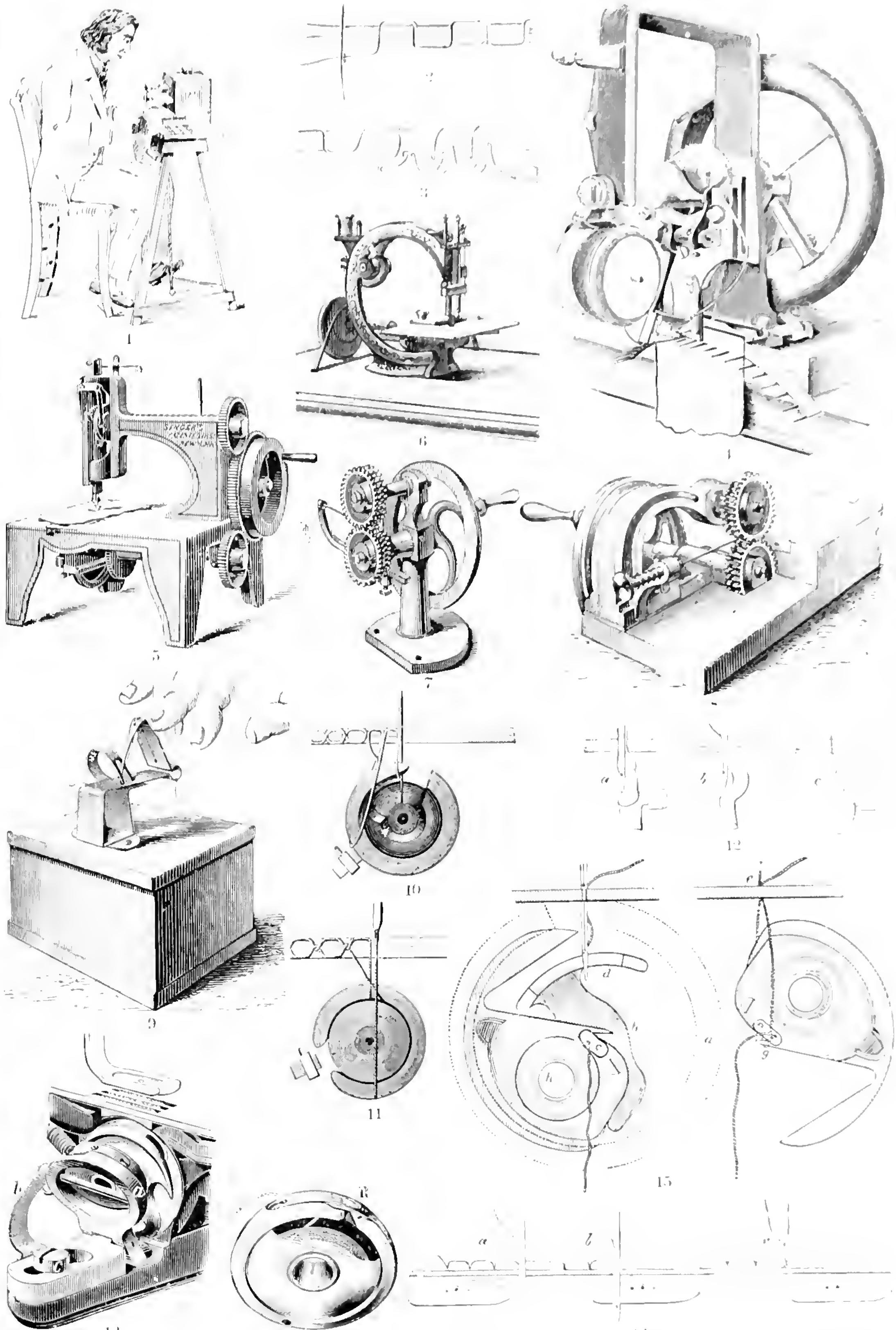
6

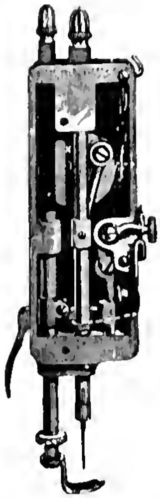
1 Rope-maker's wheel. 2. Rope-making machine 3. Ball winding machine 4. B... w... machine 5. Bobbin frame filling spooling machine 6. One of the ...



1. Thread meshes. 2. Needles of a knitting-machine. 3. Self-acting [illegible] of [illegible] 4. B[illegible] stocking-machine (James L. Branson, Philadelphia). 5. French round-frame mac[illegible] 6. N[illegible] 7. Guide and tension of Lamb's machine (enlarged). 8. Lamb's knitting-machine. 9. H[illegible] 10. Branson's machine for circular ribbed-stuff.



SEWING-MACHINES.—1. Thimonnier's sewing-machine (1830). 2. Double-pointed [illegible] 3. [illegible] stitch produced by machines in figs. 7, 8. 4. Elias Howe's original sewing-machine (1846). 5. Isaac M. Singer's [illegible] sewing-machine (1851). 6. Willcox & Gibbs' sewing-machine. 7, 8. Hand basting stitch machines. [illegible] stitch machine. 10, 11. Early form of Wheeler & Wilson's hook and bobbin. 12. Willcox & Gibbs' [illegible] 13. Rotary hook and bobbin in position, 14. Bobbin case, of the improved Wheeler & Wilson sewing-machine. 15. [illegible] lating shuttle. 16. Operation of the reciprocating shuttle.



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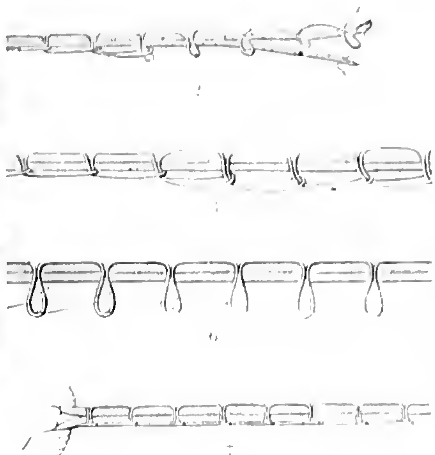

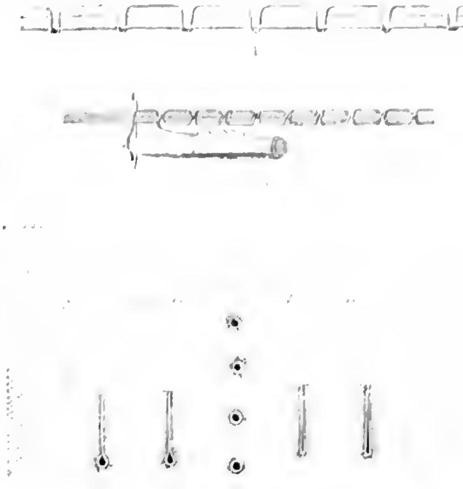

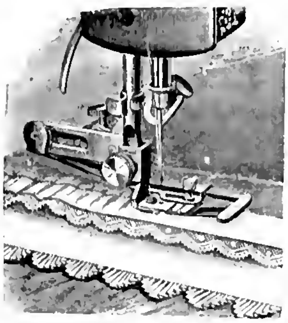

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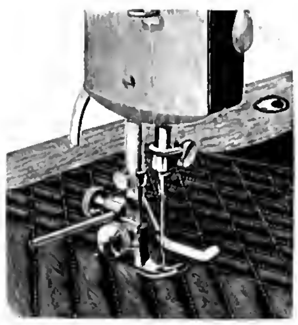

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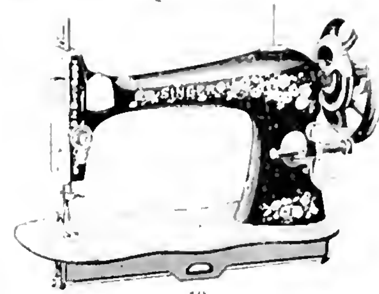

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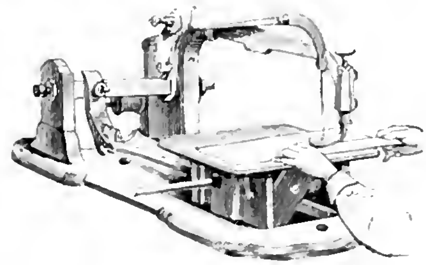

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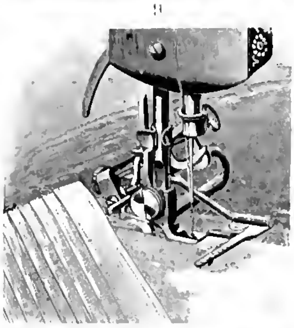

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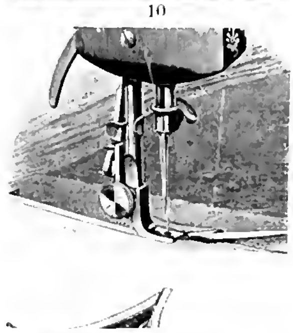

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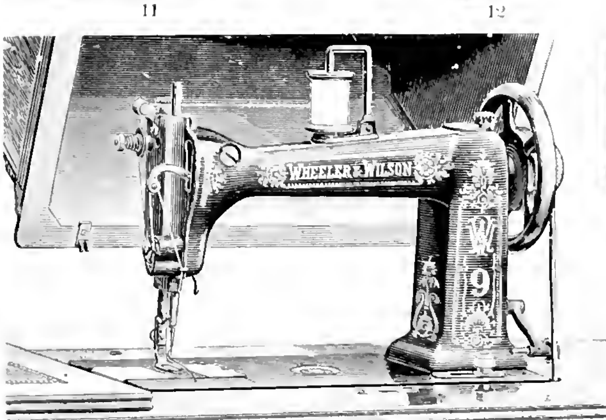

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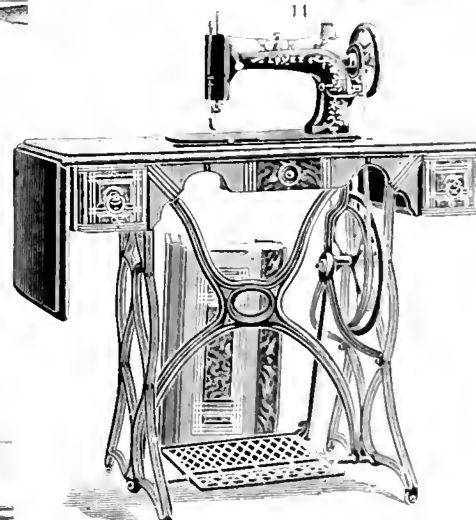
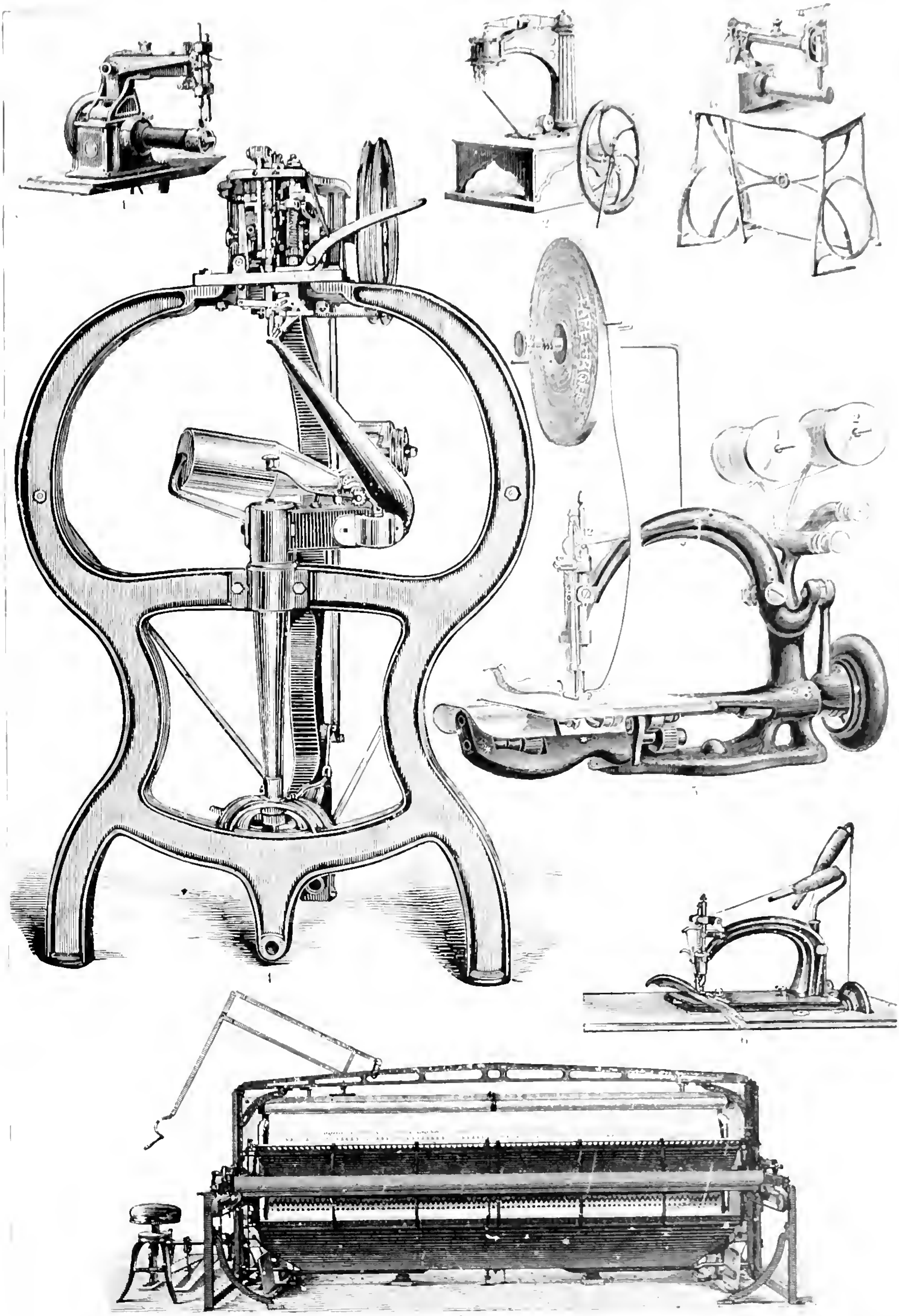
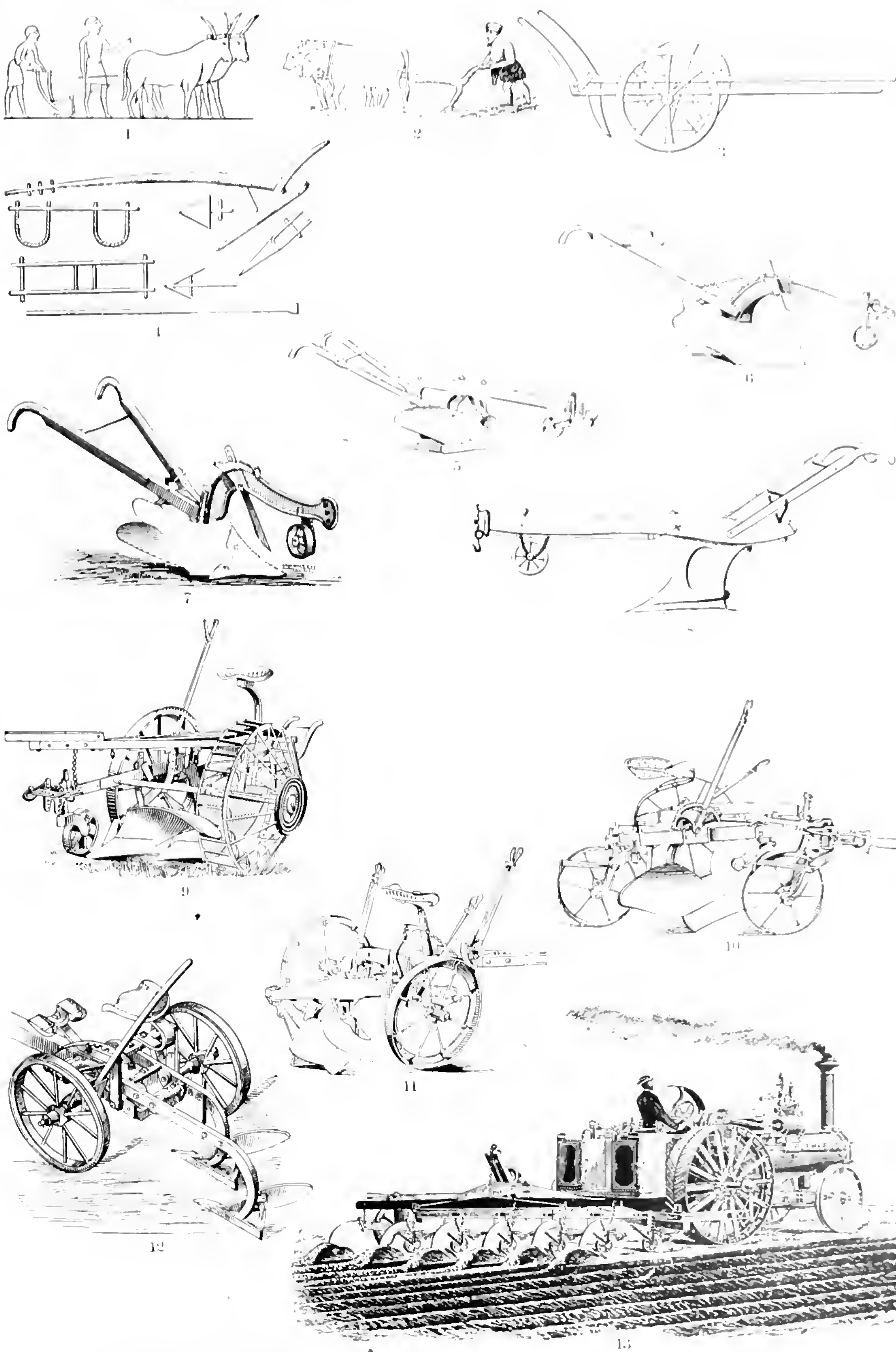


16

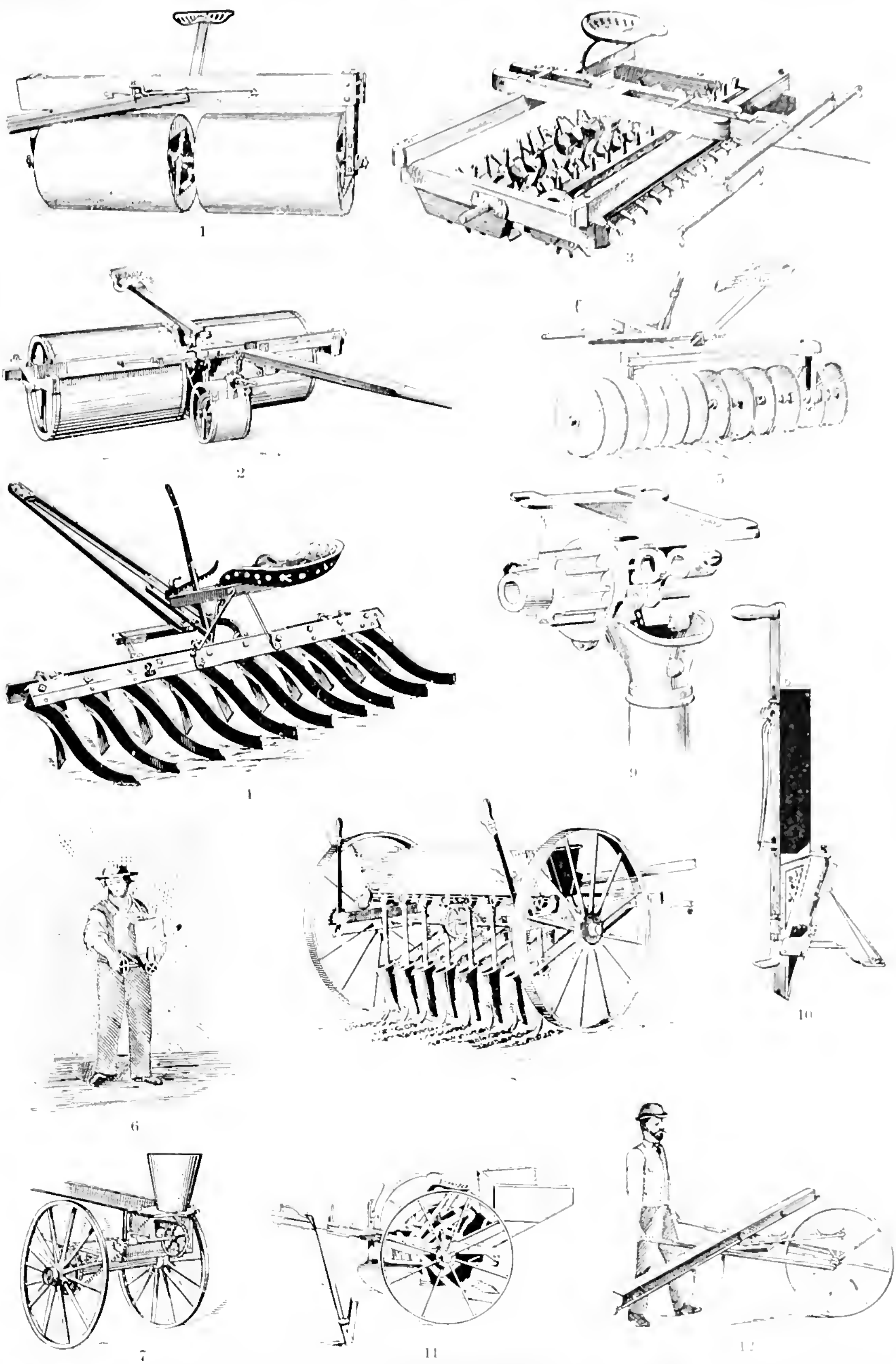
1. Head of a straight needle machine. 2, 3. Crochet or single chain stitch of the [illegible] 4, 5. Lock-stitches. 6, 7. Double chain stitch of the Grover & Baker machine. 8. Stitches [illegible] (*fig.* 10). 9-12. ATTACHMENTS: 9. Ruffler, 10. Quilter, 11. Plaiter, 12. [illegible] 13. [illegible] oscillating shuttle. 14. Early type of Wheeler & Wilson machine. 15. [illegible] 16. Button hole and sewing machine (Love Manufacturing Co., Rochester, Pa.).



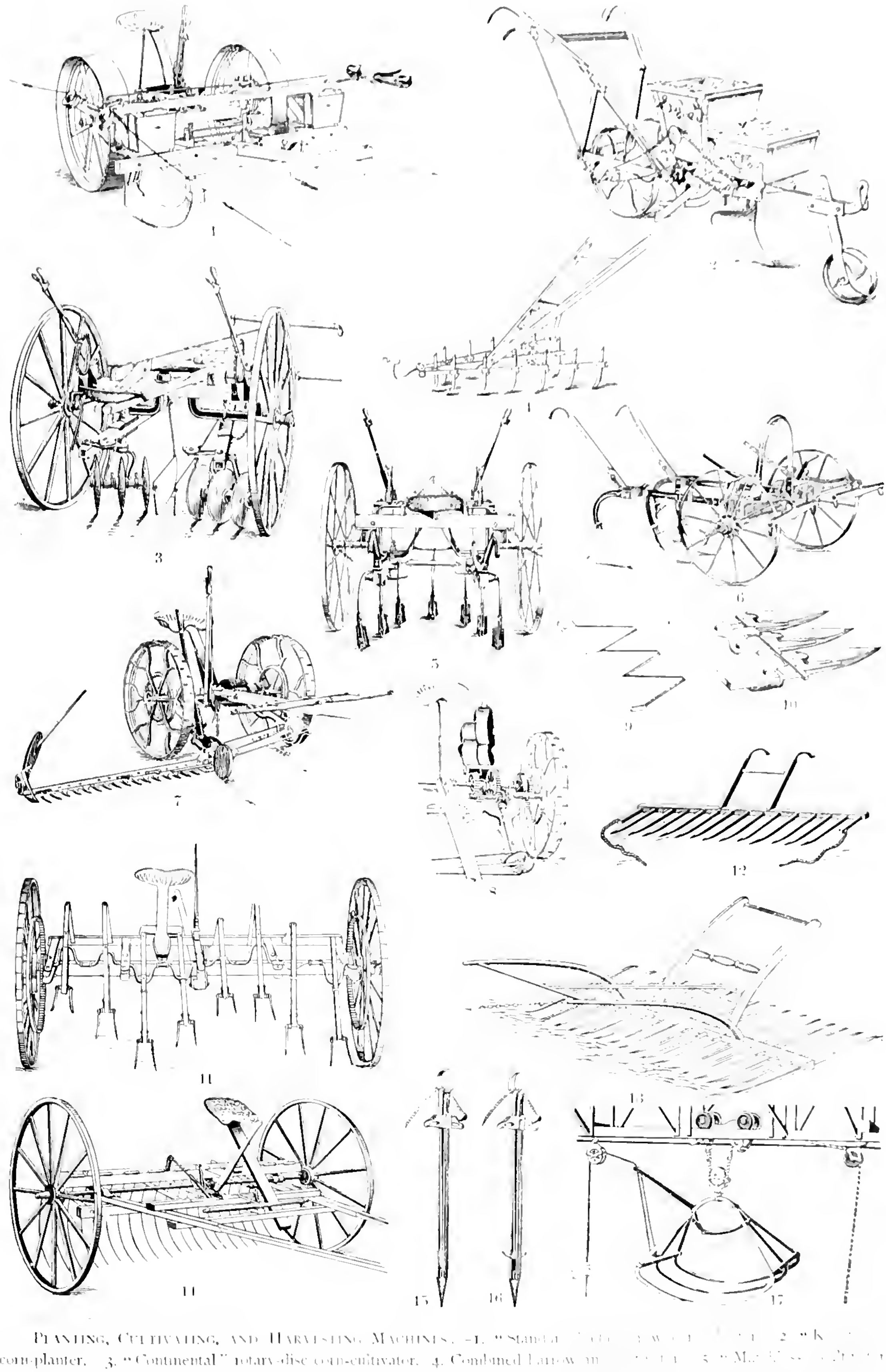
SEWING-MACHINES: 1. Cylinder sewing-machine (Wheeler & Wils[illegible] Man[illegible] Co., Br[illegible]). 2. Truncated-cone support manufacturing machine. 3. Cylinder manufacturing machine. 4. McKay [illegible] sewing-machine. 5. Double-needle machine (Kruse Manufacturing Co., New York). 6. Blanket-overs[illegible] machine (Amer[illegible] B. H. [illegible] Sewing-machine Co., Philadelphia). 7. Heilmann's embroidery machine.



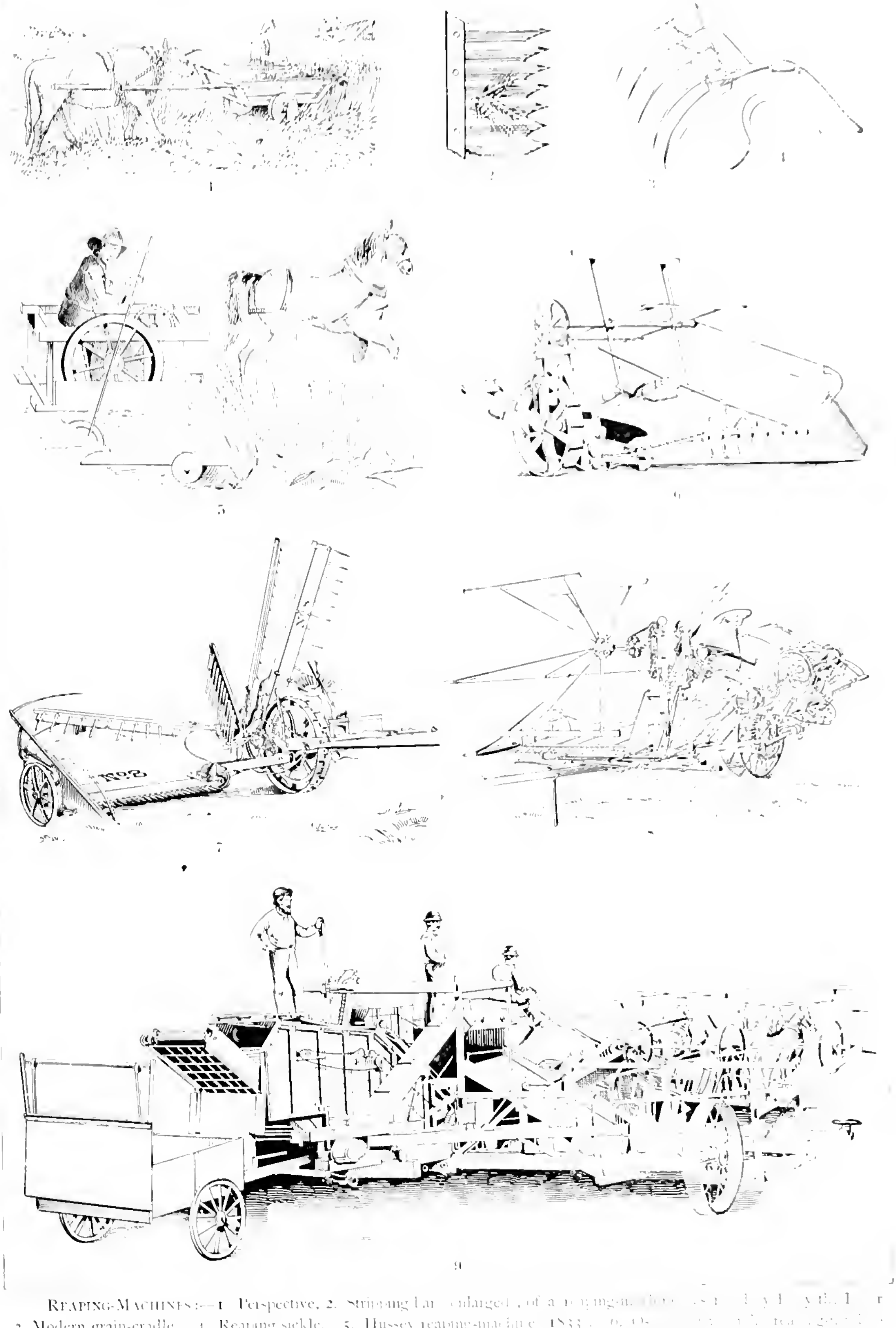
1. Ancient Egyptian plough. 2. Greek plough. 3. Greek wheel-plough. 4. Sw[illegible] 5. W[illegible] "jointer" plough. 6. Swivel plough. 7. Reversible plough. 8. Subsoil plo[illegible] 9. Sa[illegible] Garland's riding-plough. 11. Sulky riding plough. 12. Gang riding plough. 13. "Peerless" steam [illegible] Manufacturing Co., Waynesboro', Pa.).



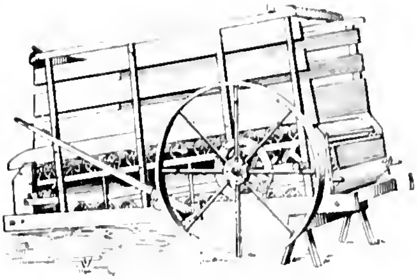
TILLAGE AND PLANTING-MACHINES:—1. Johnson's corn roller. 2. Provost's flexible [illegible] roller. 3. [illegible] stalk-cutter, clod-crusher, and pulverizer. 4. "Acme" pulverizing harrow, clod-crusher, and leveler. 5. [illegible] harrow. 6. Cahoon broadcast seed-sower. 7. Strowbridge broadcast seed sower. 8. "Buckeye" [illegible] grain drill. 9. Fluted feed-shaft, Buckeye drill. 10. Automatic hand corn planter. 11. Potato planter. 12. W[illegible] grass-seeder.



Planting, Cultivating, and Harvesting Machines.—1. "Standa[illegible]" [illegible] 2. "K[illegible]" corn-planter. 3. "Continental" rotary-disc corn-cultivator. 4. Combined harrow an[illegible] 5. "Ma[illegible]" [illegible] 6. "Buckeye" tongueless cultivator. 7. Perspective, 8. Gearing, 9. Knife, 10. Fi[illegible] [illegible] machine. 11. Hay tedder. 12. Original horse-rake. 13. Revolving horse-rake. 14. "[illegible]" [illegible] horse-rake. 15, 16. Single-bar harpoon hay-fork (closed and open). 17. Grappling hay-fork and railway hay-[illegible]



REAPING-MACHINES:—1. Perspective. 2. Stripping bar (enlarged) of a reaping-machine [illegible]. 3. Modern grain-cradle. 4. Reaping sickle. 5. Hussey reaping-machine (183[illegible]). 6. [illegible] (1855). 7. Osborne self-raking reaping machine (1882). 8. Osborne self-binding reaping [illegible] (D. M. Osborne & Co., Auburn, N. Y.). 9. "Harvest King" combined harvesting-machine (Benicia, Cal., Agricultural Works).



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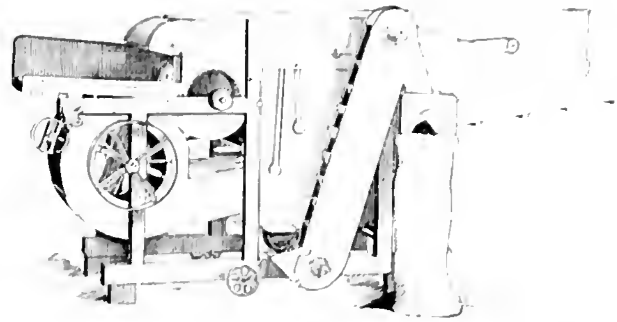

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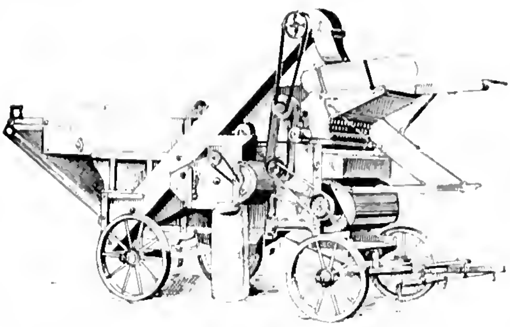

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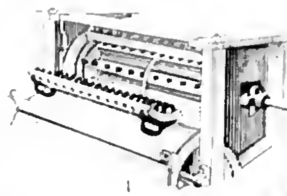

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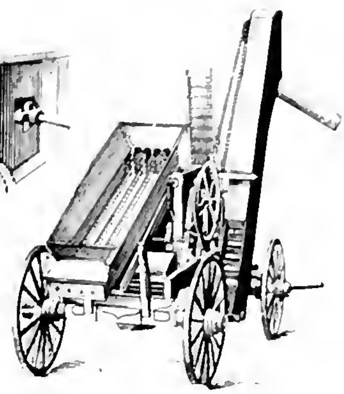

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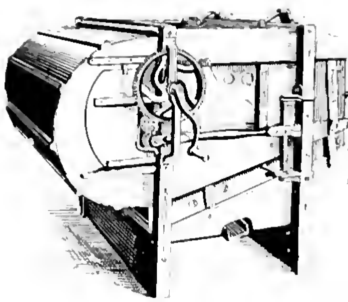

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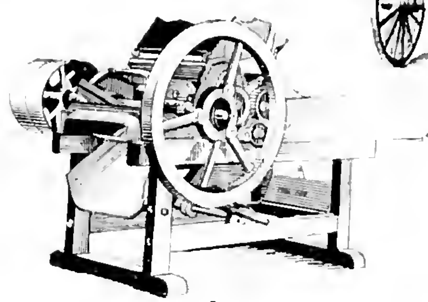

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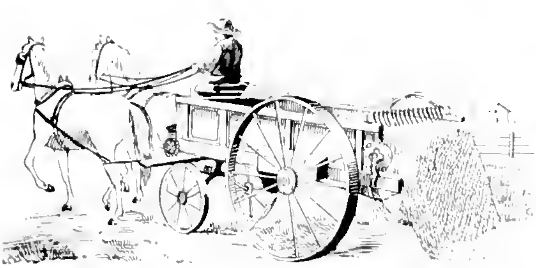

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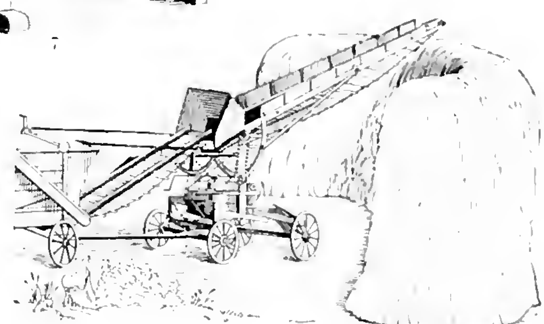

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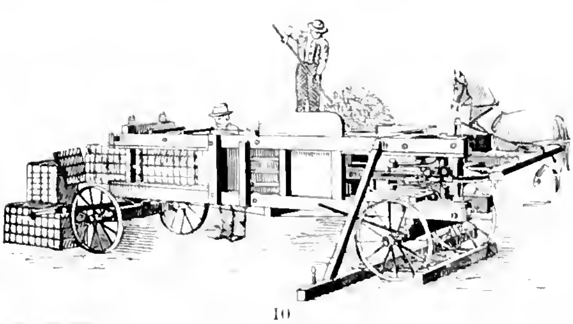

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11

1. Double-geared level-tread horse-power (Heebner & Sons, Lansdale, Pa.). 2. Thresher [illegible] cleaner. 3. [illegible] 4. Lower huller, with section of concave removed, of the "Victor" double-huller clover [illegible] (Newark M[illegible] Co., Columbus, O.). 5. Mounted geared corn-sheller. 6. Fanning mill. 7. "Ohio" ensilage-cutter. 8. Kemp's [illegible] spreader. 9. Straw-stacker. 10. "Victor" double action baling press. 11. "Planet" [illegible] potato digger.

PART II.

MOTORS AND TRANSPORT MACHINES.

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MOTORS AND TRANSPORT MACHINES.

I. EVOLUTION OF POWER.

ANIMAL organisms or mechanical contrivances which appear as the immediate sources of mechanical motion are termed "prime movers," or, in mechanical nomenclature, "motors." A motor is, therefore, the prime means of mechanical motion, or, so to speak, the motive tool. Among animate organisms considered as motors or physico-dynamic machines are included a number of animals, both men and beasts, whose muscular power is extensively utilized as a prime mover, particularly in the less advanced stages of industrial development.

Mechanical contrivances as motors may be divided into the following classes: (1) Machines which utilize gravitation, including mainly water-power motors, or hydro-dynamic machines; (2) wind-power motors, or aëro-dynamic machines; and (3) heat-motors, or thermo-dynamic machines, including steam- and hot-air engines; percussion motors, or gaseo-dynamic machines; chemical motors, such as galvano-dynamic, ammonia-gas, and other similar engines.

According to modern views of physical science, the motors must be considered, primarily as simply the vehicles of *force*.

Force is that property of matter which manifests itself as causing or resisting motion, and in its primordial form is postulated as molecular motion, the latter being assumedly due to the reciprocal attraction of the ultimate atoms of matter.

Though modern research has increased the number of the natural elements from four, as held by the ancients, to about seventy, as now recognized by chemistry, the tendency in other branches of the physical sciences has been the reverse. Thus the study of the subject has conclusively proved that the many elementary forces which were formerly supposed to "govern the world" must be considered simply as various manifestations of one elementary force, and the law which governs the change of one form of force to another has been termed the "law of the correlation of the physical forces." Every manifestation of force, whether in the form of mechanical motion, heat, light, electricity, magnetism, or chemical affinity, is now demonstrated to be but a specialized form of a single force; and this force, as already stated, is that of reciprocal attraction. It

is this force which binds together the constituent parts of every object, holds terrestrial bodies to the earth, causes the planets to revolve around the sun, and impels the suns with their systems around in the spaces of the cosmos. Thus it is this prime force which constitutes the original motive power in all so-called "motors."

That gravitation and elasticity are nothing but effects of attraction—the latter those of the attraction of the separate molecules of bodies, and the former those of the attraction of the sum of molecules composing them—needs no further explanation. But steam-power and the expansive power of gases are in the first place the effects of heat, which in its turn is an effect of the reciprocal attraction of the atoms of matter or of the ether surrounding matter—in other words, of *molecular motion*. All other forms of force, such as light, electricity, etc., have been proved to be but varying conditions of this molecular motion, and thus it follows that all force, whether it be muscular power (independent of the idea of will or consciousness) or any other form of motive power, can be completely traced back to the prime element of atomic motion, or molecular attraction. However complicated the combination of proximate causes and effects, all can finally be deduced from the one cause named.

Thus water-power is the result of a series of changes, each change being the effect of a preceding cause, which in its turn is an effect of an antecedent cause, and so back to the original condition of force in the form of molecular motion. A certain quantity of water flowing downward from a height by reason of the attraction of the earth, produces a mechanical effect corresponding to the height of fall; but when all has reached its level, no further effect is possible without a further change involving an expenditure of force to bring about the change. To continue the same mechanical effect as before, the water must again be raised to the height. This, in nature, is accomplished through the agency of the sun's heat acting in conjunction with that of the earth, which produces evaporation into the atmosphere. The changes of day and night cause changes in temperature: when the latter lessens, the evaporated water condenses, is precipitated from the clouds, falls to the earth by reason of the attraction of gravitation, and, collecting at various levels, renews its downward flow and its mechanical effect; and thus the force of heat, obtained in this case, as we have noted, directly from the sun and from the earth, is translated into the mechanical effect of the descending water. In like manner all other mechanical effects can be traced through a variety of causes to the force of heat, which, as has been observed, is a state of atomic motion.

Nature furnishes us with ready motive power in the shape of moving air and water. All other forms of mechanical motion, not excepting muscular power, require the application of heat, and this, practically in all cases, is obtained through combustion. In modern times heat motors have almost wholly superseded all others, and the department of thermodynamic machines comprises, therefore, by far the most important class of motive tools.

I. PHYSICO-DYNAMIC MOTORS.

The animal, including man as such, represents the motive machines to to be considered in this section. Strictly considered, their treatment would naturally include descriptive anatomy and physiology.

By a comparative analysis the analogy between the working animal and the steam-engine becomes apparent. Like the steam-engine, the animal must be supplied with water and with substances containing carbon and hydrogen. These substances are furnished to the animal in the natural form of grass, grain, and other vegetables, and also in animal foods capable of free assimilation; but to the steam-engine or the caloric motor the potential energy is supplied in the form of wood, coal, or some other combination of carbon and hydrogen. In the animal as also in the caloric machine the carbon and the hydrogen are chemically converted into carbonic acid and aqueous vapor, which, both from the animal and from the machine, are expelled as waste matter. In both motors the elements incidentally present in the combination of carbon and hydrogen, such as calcium, phosphorus, iron, sodium, etc., are likewise given off to a greater or less extent in the form of excreta in the animal and of ashes in the machine. In both, heat is developed by this chemical conversion or combustion, and in the animal as in the caloric engine a portion of the heat is wasted by radiation, etc., or by being passed off in the expelled substances, while another portion is utilized for power, or, expressed differently, produces mechanical effect.

From the quantity of carbonic acid and vapor a human being expels, according to physiological observations, and from the mechanical effect he at the same time develops, according to technological observations, there has been calculated the degree of efficiency or the degree of effect which the human animal exhibits as a thermo-dynamic machine; and the surprising and interesting result has been obtained that in this respect he fourfold surpasses the steam-engine. This calculation, however, refers only to the degree of effect of the heat developed in the interior of these two motors thus compared, and is hence only scientifically correct. Practically, the fact has to be taken into consideration that the carbon and the hydrogen in the soluble form of animal food are more costly—in other words, entail more labor in their production—than is coal or wood, and that the human motor cannot, like the steam-engine, be fed with insoluble fuel, and, moreover, requires food not only for the production of mechanical force, like the steam-engine, but also for nourishment.

A theory regarding the life and the force of animals from the standpoint of thermo-dynamics, considering the anatomical structure of skeleton and muscles on a basis analogous to the theory of the steam-engine, was attempted as far back as 1660 by the Italian physician Borelli. The boldness of this attempt, arising from the self-confidence which is incident to the youth of mechanical science, stands, however, in the same relation to the success attained as did the efforts of the Greek philosophers to con-

struct the science of natural objects *a priori* through speculation, which gave way only to the Galileoic system of research, advancing laboriously and gradually through experiment to knowledge.

The study of the animal as a machine has become entirely empiric, and its theoretical treatment, being practically barren of results, has been almost totally abandoned. It has been observed that the mechanical effect produced by a physiological motor differs very essentially in the performance of the following operations—namely, turning a crank, pressing a lever, pulling on a rope, pushing a bar, walking in a tram-wheel, ascending a step-wheel, or treading a tread-wheel. It has also been observed that the effect produced by the animal materially depends on the velocity with which it has to turn, push, lift, or tread, and that the number and the duration of the stoppages allowed for recuperation also form an important factor. Generally speaking, the results of these observations demonstrate that the physiological motor works best with a velocity which is half as great as the utmost speed attainable by the animal without having to overcome resistance, and these results completely harmonize with those reached in regard to nearly all other motive machines.

Eight hours per day have been proved to be the most favorable duration of time for the labor of both man and beast. The unit of work or labor is usually the horse-power. One horse-power is the equivalent of 33,000 foot-pounds of work done per minute or 550 foot-pounds per second. From the following data James Watt made this the standard for estimating the power of a steam-engine: If a horse walk upon level ground at the rate of two and a half miles per hour, he can continually during his working-day pull with a force of one hundred and fifty pounds. This was the work of the average horse employed in raising ore out of a mine. Now, two and a half miles per hour is a speed of 220 feet per minute, and $220 \times 150 = 33,000$—that is, the product of a certain number of pounds lifted vertically at the rate of a certain number of feet per minute; hence the expression "foot-pounds," which has become the fundamental unit of work. In course of time steam-engines took the place of horses at the mines, and the naming of the power of any engine was in accordance with the number of horses whose work it did. For the sake of simplicity in having one unit, the work of men and that of animals are compared to the horse-power.

The continuous work in eight-hour periods of a man turning a crank has been fixed at fifteen pounds at a speed of 220 feet per minute, which is $220 \times 15 = 3300$ foot-pounds, or $\frac{1}{10}$ of a horse-power. Other applications of a man's hands, feet, and body doing work have been fixed at the same figure, although experimenters arrive at different results.

It must be observed that there is an essential difference between the manner of working by animals and that of working by machines. The organic motor works wholly and most effectually by intermissions. The stress of fifteen pounds applied to the crank is not uniformly applied all the way around the circle, but by pushing and pulling the crank the ope-

rator, by the efforts expended upon all the quarters of the circle, has furnished the equivalent of fifteen pounds. In treading, the action is step by step in a similar intermittent way.

Tread-, Tram-, and Step-wheels.—In Figures 1 to 3 (*pl.* 61) the weight of the physiological motor is applied as the motive power similarly to the tread-plane (*fig.* 4), but more completely. In the tread-wheel (*fig.* 1) the weight of the workman is applied to the periphery of the wheel at the top, while in Figure 3 it is applied to the interior of the wheel at the bottom. In both cases the movement of the workman, laboring to ascend a "circular stair," but always retaining the same position, rotates the wheel and its shaft. In the step-wheel (*fig.* 2), however, he endeavors to climb a "circular ladder," but by likewise remaining in the same place on the circumference of the wheel causes the latter, with its shaft, to revolve. The manner in which the weight of the physiological motor becomes effective with these wheels may be more clearly understood by imagining an ordinary stair placed beside the wheel. The workman ascends the stair and, stepping upon the upper step or round of the wheel, causes the latter to rotate by quietly standing on the step and sinking with it. Wheels of this description have been constructed and successfully worked by a number of workmen successively ascending the stair and sinking with the motion of the wheel. In this case, however, there appears a combination of muscular power and gravity.

The Horse Tread-plane (*fig.* 5) is in a certain sense a horse-power with a relative movement of the motive animal to the path. While in operating the latter machine the horse walks around upon a fixed circular track, in the tread-plane the track rotates beneath the stationary animal and is secured to a shaft driving a toothed gearing. That the weight of the animal may also be made effective, the track and the shaft are somewhat inclined.

Horse-powers.—Figure 6 represents a portable horse-power machine enclosed by an iron casing. The transmitting shaft in the horse-track is exposed. To prevent the horses from treading upon or from stumbling over it, the shaft is covered in the track of the horses, and is connected with the horse-power by a so-called "universal joint" which admits of its being shifted into other positions. The machine appears externally as a closed casing which protects the internal gearing from rain and dust. When in use, the machine is secured to a foundation of crossed timbers. Figure 7 shows an American mounted horse-power, a machine that can be used without dismounting it from the wheels on which it is moved from place to place. It is operated by long levers which are suitably connected with the master-wheel and to which the horses are attached. The master-wheel actuates a gearing which in turn drives the tumbling-rod that transmits the power to the working machine. Figure 1 (*pl.* 60), a description of which is given on page 188, shows an inclined-plane horse-power designed for different kinds of work on the farm, more particularly as a motive power for thrashing-machines.

II. HYDRO-DYNAMIC MOTORS.

1. WATER-WHEELS.

The water, being raised through evaporation into the atmosphere by the heat of the sun and of the earth, and after precipitation as rain and snow being drawn into the valleys by the attraction of gravitation, is made available for motive power in the latter track of this circuit through the agency of wheels (1) by its impact acting against their projecting parts or paddles, so placed as to receive the force of the current; (2) by its weight being delivered in quantity in receptacles, called "buckets," formed in the rims of the wheels; and (3) by its reaction or counter-force, which becomes available when the water, after being delivered into the wheel, is permitted to escape in a direction opposite to that which it had when entering the wheel.

Classification.—Water-wheels may be chiefly classified into (1) those which turn on a horizontal axis and (2) those which turn on a vertical axis. To the first class belong the overshot-, undershot-, and breast-wheels, and to the second class belong the reaction-wheels and the turbines. As the turbines constitute the most efficient variety of water-wheels and are probably the most numerous, hydro-dynamic motors will be separately considered under the subject-heads of (1) water-wheels and (2) turbines.

Current-wheels.—The application of the force of moving water as a motive power is of early Eastern origin. The current-wheel or *noria* (Arabic, *na'ura*) has for thousands of years been employed in Egypt, Arabia, and Syria for raising water for purposes of irrigation. The periphery of the wheel has radial floats, which are sufficiently submerged to be acted upon by the current of the water and to give rotation to the wheel secured upon its horizontal axis. (See p. 200.) The first mentioned floating current-wheels for driving machinery were those used to turn the corn-mills which were devised by Belisarius when the Romans were besieged by Vitiges. (See p. 34.) In 1802 there was patented by Hawkins of England a current-wheel which was substantially a reinvention of the current-wheel of Belisarius.

The Overshot-wheel, shown in Figure 1 (*pl.* 62), is constructed entirely of iron, and is built upon a wrought-iron axle or shaft (*A*), which rests on each side in a journal (*C*) secured to and supported by the masonry. In immediate connection with the shaft are three equidistant hubs, to which radial arms (*B*, *E*, *D*, *F*) are fastened and braced diagonally by stay-rods (*B*, *G*). On the periphery of the wheel numerous curved plate-iron buckets are formed and arranged for the reception of the water, and on one end is secured a spur-gearing ring which engages with the small cog-wheel (*M*) of the transmitting shaft (*N*).

The High Breast-wheel (*fig.* 4) is also constructed of iron, and in addition to the radial arms, as in Figure 1, it has "brace-rods," which

are connected to the two large cast-iron hubs, and also to the cast-iron rims. The construction of the buckets, which is similar to that of Figure 1 (*pl.* 62), is shown in enlarged section in Figure 5. The continuous cog-gear on the interior of the rim of the wheel engages with the gearing, shown at the left of the illustration. Above the water-channel or race is seen the self-acting ball-governor, which regulates the sluice-gate, and hence also the water-supply and the speed of the wheel. The human figure represented in the illustration is intended to give a comparative idea of the size of the wheel, which was constructed to operate a cotton-mill in Greenock, Scotland. It has the enormous diameter of over 21 metres (69 feet) for a height of fall of 19½ metres (64 feet), and is but little smaller than the largest known water-wheel. The overshot-wheel employed for working the pumps which drain the mines at Laxey, on the Isle of Man, is perhaps the largest water-wheel in the world. It is 72½ feet in diameter, with a width of 6 feet, and exerts a force of about two hundred horse-power. The crank-shaft is 10 feet long, and the pump has a capacity for raising two hundred and fifty gallons of water per minute from a depth of 1200 feet.

The Middleshot-wheel, represented in Figure 2, is also of cast iron, but is provided with wooden floats or paddles laid across the periphery of the wheel. To retain the water as long as possible in the spaces between the paddles, a circular channel (*A*, *B*, *E*) closely encompasses a portion of the wheel. This channel is not required for overshot-wheels, but it is an indispensable part of high breast- and middleshot-wheels. It is constructed either of wood, as in this example, of iron, or of masonry. The sluice-gate, which is secured to a pivoted horizontal rod, is adjusted by a rack and pinion (*S*, *D*). Instead of allowing the water to run in between the circular channel and the bottom of the sluice-gate, as in Figure 2, there is employed a so-called "overflow" sluice-gate, which shuts off the water on the bed of the channel and forces it to pass over the gate (*pl.* 63, *fig.* 10). The construction of the wheel in Figure 10 is very nearly like that in Figure 2 (*pl.* 62), it having, however, wooden shrouds and wooden arms set in cast-iron hubs, and for transmitting its power is further provided, like Figure 4, with a cog-wheel, which is supported by radial rods.

Undershot-wheels: Poncelet Wheel.—The circular channel of undershot-wheels is necessarily short or is entirely omitted; otherwise their external appearance is generally the same as that of a middleshot-wheel (*fig.* 2). Figure 4 (*pl.* 63) exhibits a peculiarly-constructed wheel (called the "Poncelet wheel" after its inventor) which in this case is of iron and provided with curved plate-iron buckets so constructed that by the aid of the sluice-gate the water is forced to impart to them almost its whole force by impact. The water is directed down a slope or curved race and enters the wheel with the full force of its current. Gliding up the curved buckets, it comes to rest, falls back, and at the point of discharge acquires a backward velocity nearly equal, relative to the wheel, to the forward velo-

city. The diagrammatic lines drawn on the lower part of the wheel, which is shown as cut away, are intended to illustrate the action of the water in the latter respect.

Zuppinger's Wheel.—A more recent construction—designed, however, for a greater height of fall—is Zuppinger's wheel, shown in Figure 3 (*pl.* 63). It consists of a single rim (*A*, *B*) and of long radial sheet-iron buckets, which are secured on one or on both of their sides, but are enclosed top and bottom by a casing (*D*, *E*, *F*, *G*, *H*, *K*). This casing, which admits the water sidewise into the bucket, prevents its escape until the buckets have reached their lowest position (*H*, *G*), thus securing a high degree of effect.

Sagebien's Wheel (*figs.* 1, 2) is designed more completely to utilize the power of the water by receiving its entire momentum without loss of the height of fall—that is, without lowering the head surface of the water. Externally, Sagebien's construction somewhat resembles the Poncelet wheel (*fig.* 4), the water in the former, however, being admitted over an overflow sluice-gate. As, in many cases, this form of construction involves the use of very large, and consequently expensive, wheels, the inventor devised the wheel with a smaller diameter, shown in the Figure, which is nevertheless also rendered costly through its complicated structure. As will be seen from the plan (*fig.* 2), the water, instead of being admitted to the periphery, flows in on both sides of the wheel. To secure this object the paddles receive a peculiar construction, and, though rather expensive, have the advantage of completely utilizing the power of the water. The elevation (*fig.* 1), which exhibits the upper part of the head race in section, will convey an idea of this method of constructing the paddles. The moving water, moreover, can be admitted to one or to both sides of the wheel, as desired, by opening one or both of the sluice-gates placed in the fork of the channel.

Floating Wheel.—As a substitute for the current mill-wheel Professor Colladon of Geneva invented what may be called a "floating" current-wheel (*pl.* 62, *fig.* 3), which consists of a circular iron body or drum provided on the outside with paddles. The drum, being hollow, floats on the surface of the stream and is rotated by the running water. The manner of setting the wheel and of connecting it to the machinery it is intended to drive is as follows: The pillow-block for the transmitting shaft leading to the bank of the river is placed in a frame of beams, whose lower ends are secured in the bottom of the river. Extending horizontally from this frame are two movable cast-iron arms, between which is arranged the cylinder-like wheel. On one of the arms is fixed a centre gear-wheel, which engages with the spur-wheel of the drum and with the cog-wheel of the transmitting shaft; hence it will be seen that, notwithstanding the rise or the fall of the water-wheel with every fluctuation of the water-line, no injury results to the transmitting shaft by reason of its fixed position. The inventor has also placed a floating race under the wheel. The cross-section of the current of the stream being reduced by means of the race

and the submerged frame and water-wheel, the velocity of the water is considerably increased, whereby a higher degree of power is obtained.

The connection by means of screw-bolts of an iron radial arm with the iron rim of a wheel is shown in Figure 5 (*pl.* 63), and in Figure 7 the connection of the iron and wooden ventilated paddles with the rim. The purpose of the latter is to permit the escape of the entrained air in the buckets of overshot- and high breast-wheels, and to obtain the fullest effect of the inflowing water.

In Figures 6, 8, and 9 is given, in sections, the manner of connecting the iron or steel "pivot" with a hollow cast-iron shaft (*fig.* 9), one of plate iron (*fig.* 8), and one of wood (*fig.* 6), the latter showing also the method of securing upon a wooden shaft a cast-iron hub centred with screws.

The Pelton Water-wheel (*pl.* 64, *fig.* 1), invented by L. A. Pelton, occupies a position between a water-wheel proper and a turbine. This water-pressure motor is largely employed in the mining districts of the Pacific coast, where it utilizes the water-power of the mountain streams. The periphery of the wheel, whose shaft rests in bearings on a timber framework, is set around with metallic buckets, to which the water, under pressure, is directed from a nozzle so set as to deliver the water parallel with the wheel. Each of the buckets has a partition which divides the impinging stream of water, and, being open with a free discharge, the buckets are not obstructed by leaves, roots, etc., nor by ice if the wheel be kept running. In point of efficiency, the highest theoretical results claimed to be due to water-power (85 per cent.) are realized under all heads of fall and every variety of application, while under favoring conditions it reaches as high as 90 per cent. or 92 per cent.

"One of the most remarkable instances of electrical transmission of power has recently been accomplished on the world-famous Comstock Lode, Nevada, and the almost equally famous Sutro Tunnel. At the Nevada Mill there is a 10-foot Pelton water-wheel, which receives water through a pipe-line delivering water from the side of Mount Davidson under a head of 460 feet, giving two hundred horse-power. Here the water is caught up, delivered into two heavy iron pipes, and conducted down the vertical shaft and incline of the Chollar mine to the Sutro Tunnel level, where it is again delivered to six Pelton water-wheels, this time running under a head of 1680 feet. Each of the six wheels is but 40 inches in diamter, weighing 225 pounds, but with a jet of water less than ⅝ of an inch in diameter they develop one hundred and twenty-five horse-power each. On the same shafts, which revolve nine hundred times a minute, are coupled six Brush dynamos, which generate the current for the electric motors that drive the stamps in the mill above ground. The result is that, where it formerly took 312 miners' inches of water to operate thirty-five stamps, but 72 inches are now required to run sixty stamps. This is the most enormous head of water ever used by any wheel, and by itself constitutes an era in hydraulic engineering. A bar of iron thrown

forcibly against this tremendous jet rebounds as though it had struck against a solid body instead of a mobile fluid. The speed of this jet, where it impinges against the buckets of the wheel, is two miles per minute, or 176 feet a second."

Water Motors.—By applying to a working machine the principle of the force-pump (see p. 328), this transport machine can be converted into a motive machine by simply reversing its action—that is, instead of the delivery-valve being raised and the water pressed into an ascending pipe by the movement of the plunger-piston actuated by a separate motive power, the delivery-valve can be raised by external means and the piston moved to and fro by discharging, after each stroke of the piston and the filling of the cylinder, the contents of the latter by opening the suction-valve. The water here appears, not as a transported mass lifted at the expense of motive power, but as a motive substance which subsides with the production of the mechanical effect.

Water-pressure Engines.—Machines constructed according to the above principle are called "hydraulic" or "water-pressure" engines, in which water under pressure drives a piston in a cylinder somewhat in the manner of steam. They essentially differ, however, from piston-pumps in their mechanism, through which the opening and closing of the valves are automatically effected by the engine itself, as also in appliances which are better adapted to the purpose than pump-valves, and through which the supply and discharge of the water can be regulated.

In a water-pressure engine there exists the following principal parts: (1) the *head-race*, consisting of a supply-pipe leading from a reservoir to the working cylinder, which pipe, together with the reservoir, constitutes what is called the "pressure column;" (2) the *regulator*, a valve which is capable of being adjusted to any required extent of opening; (3) the *engine* proper, consisting of a *piston* moving in a *cylinder* together with the *distributing-valves* for admitting and discharging the water from the cylinder; and (4) the *tail-race*, consisting of a *discharge-pipe* whose final outlet may be either at or below the level of the cylinder.

When a water-pressure engine is spoken of without qualification, a self-acting engine is generally meant—that is, an engine which differs from a mere hydraulic press, hoist, or crane in having distributing-valves for regulating the supply and discharge of the water, which valves are moved directly or indirectly by the engine itself, so that it is a machine which has a periodical motion, and which, having once been started, goes on of itself until it is stopped either by shutting the regulator and so stopping the supply of water, or by disengaging or otherwise stopping the valve-motion.

The water is admitted to the cylinder at high pressure and discharged at low pressure, consequently the work done on the piston causes a reciprocating action. The useful work is due to the difference of the pressure of admission and the discharge, whether the pressure is due to the weight of a column of water whose source is of more or less considerable height,

or is artificially produced. In default of a natural head of sufficient power, the head is established in an accumulator of power, which is a body of water driven into a reservoir by forcing-pumps operated by steam. When the water is said to act *by pressure*, the pressure which drives the piston is not simply the effect of the weight of a portion of water which descends, but is the effect of the weight of some more or less distant mass of water transmitted through an intervening mass and diverted to any extent in direction or modified in the velocity of its action.

The motion in these machines never acquires a high velocity on account of the non-elastic nature of water, which prevents its being used expansively like steam or air, but, for the most part, on account of the kinetic energy of the water being wasted, with the result that hydraulic engines use as much water when running idle as when working at their full power. An engine is single-acting if the water acts on one face of the piston only, and double-acting if the water acts on each face alternately. The valves are sometimes worked by a small auxiliary water-pressure engine, and sometimes by hand, in which latter case the same valve may act as the regulator and the admission valve.

In the rotative class of engines the cylinders are either double- or single-acting, and the piston-rods drive a shaft by means of connecting-rods and cranks. To diminish as much as possible the variations of the effort upon the crank-shaft, it is usual to have two, three, or four cylinders acting in succession; but a single cylinder will answer if the fly-wheel is of sufficient inertia.

Water-pressure engines were invented by Höll in Hungary in 1749, and at nearly the same time (1753) in Germany by Winterschmidt, and later (1765) in England by Westgard. In 1809 they were so improved by Von Reichenbach as to answer their purpose more perfectly, being almost exclusively employed in mine-drainage. This limited application of the water-pressure engine is due, on the one hand, to the necessity for a considerable fall of water, on which its effectiveness depends, and, on the other hand, to the necessity for an intermediary mechanism to convert the slow reciprocating motion into a rotary motion, which, though it causes loss of power and additional expense, is generally required. The pipe-conduit system of water-distribution in cities from elevated reservoirs, with a pressure equal to a fall of from 30 to 60 metres (100 to 200 feet), opened up a new field for the extended use of such engines, but it was not known how to impart a greater velocity to the piston and how to change its slow reciprocating motion into the requisite rotary motion by means of some simple mechanism, until Ramsbottom of England produced his small rotary water-pressure engine as shown in Figures 3 and 4 (*pl.* 64). This motor consists of two vertical cylinders oscillating on a central axis, which operate one crank-shaft by means of two cranks at right angles to each other. Figure 9 shows how the surfaces of contact between the two cylinders and a central post, in which the inner trunnions are journaled, are made water-tight by two adjusting screws (in the hous-

ing frame) pressing the cylinders against the central piece, which is also connected with the frame. The water is conveyed to the cylinders through the central post and through the channels cast on the cylinders, first over and then under the piston, and is discharged. The alternate induction and eduction of the water from the centre post to the cylinder channels are effected by the oscillation of the cylinders. The Ramsbottom engine is largely used in England for the lighter industrial purposes, such as operating printing-presses, lathes, etc., and combines the advantages of simplicity, compactness, safety, and economy.

The Swiss engineer Schmid invented an improved form of water-pressure engine which attained a degree of utilization of the water power of 80 per cent. Schmid's construction is a horizontal single-cylinder oscillating engine (*pl.* 64, *fig.* 2). On the lower side of the horizontal cylinder is a convex projection which forms the arc of a circle and which fits water-tight in its concave bed. In this projection and leading to the piston are the water-channels, which automatically become alternately induction and eduction passages by the oscillation of the cylinder. The water-supply is conducted to and the discharge received from the cylinder by suitably arranged pipes in the bed of the machine. In competition with a number of other water motors, mostly turbines, Schmid received the prize offered by the city of Zurich in 1876 for the best hydraulic motor for utilizing the power of a city water-conduit for small industries.

Figure 6 illustrates an American water-pressure engine, which is extensively employed for supplying house-tanks with water where the pressure in the street-main service is not sufficient in itself to force the water to the tanks. A certain proportion of the water from the main in such cases is used to drive the motor and to lift a smaller proportion to the tank. In construction the engine does not materially differ from a steam-pump (p. 331), except that the driving cylinders are provided with ports and pistons suitable for water-pressure. In the larger sizes the driving cylinder-valves are balanced; such engines are constructed with proportions suitable for any condition of service, and are capable of supplying towns or cities with water.

Backus Water Motor.—Figure 5 exhibits a class of water motors adapted for driving light machinery, such as lathes, sewing-machines, etc. They are constructed on the principle of the application of a water-wheel in a case; their action, however, depends upon the impact of the water under pressure, and not by its weight. The greater the elevation of the reservoir or the stand-pipe the higher the speed. The water-jet of the smallest type of these motors has a diameter of but $\frac{1}{16}$ of an inch. Their general points of excellence, briefly stated, are availability, steady motion and noiseless operation, safety and freedom from derangement, and economy of water.

2. TURBINES.

While the use of the water-wheel, whose inventor is unknown, can be traced back to a period before the Christian era, the turbine, though for several centuries known and employed in some imperfect form of construction, belongs to the present century. Its development, which was based somewhat on theories, from its crude primitiveness into a construction that could stand the test of perfected technical knowledge, and its introduction into a wider sphere of usefulness, however, date only from Segner's invention in 1740, and from the mode of construction proposed by Euler in 1754.

Turbines (from *turbo, turbinis*, a top or whirl), also known as vortex wheels, utilize water-power by the effect of the impact of the water, and in addition to this by its reaction, and never, as with the water-wheel, directly by weight. Like water-wheels, however, turbines consist of wheels provided with paddles or buckets, and shafts for guiding their rotation and for transmitting their power to a convenient place for its application; and while the water-wheels permit the moving water to escape at the side on which it is received, in the turbines it passes through and escapes on the opposite side. Turbines were originally constructed only with vertical shafts and horizontal wheels. They were called "horizontal" water-wheels, in contradistinction to the hydraulic motors illustrated on Plates 62 and 63, which were termed "vertical" water-wheels. Since, however, turbines with horizontal shafts and vertical wheels have for some time been constructed—as, for example, Figure 3 (*pl.* 68)—this designation is no longer correct. Turbines are classed as outward-flow, inward-flow, and parallel- or downward-flow wheels, according to the direction taken by the water in passing through them. The turbine was introduced into general use by Fourneyron in France in 1827, and soon after by Fairbairn in England and by Boyden, Parker, Swain, and others in America. The varieties of turbines at present in operation throughout the United States are numerous, covering, perhaps, every known form, mode of action, and direction of water-flow through them.

The development of the two principal types of turbines now in use is based on the inventions of Segner and Euler, and doubtless the perfection of a third type, which as regards external appearance and mode of action is an outgrowth from the older constructions, is due to the zeal for improvement aroused by these two inventions, which are based on the principle of hydraulic reaction. This phenomenon of the reaction of flowing water, first observed, as is generally supposed, by Bernoulli in 1730, is exemplified in the Barker mill (*pl.* 3, *fig.* 6), which consists of a vertical vessel or tube provided with horizontal discharge-pipes, which receive by the outflow of the water a pressure in a direction opposite to the outflowing jet. (See p. 37.) The first one to apply the double sources of power, impact and reaction, to turbines was Fourneyron.

Segner's Reaction Turbine.—Segner combined the tube with a vertical

shaft which could be freely turned on a pivot, and its rotation was effected by placing the aperture of the discharge-pipe at a point farthest from the shaft and in such a manner that the jet flowed out tangentially to the circles described around the shaft. In another construction, employed for driving a flour-mill in Nörten, near Göttingen, he provided the lower portion of a tall vessel secured to a vertical shaft with four radial tubes, each of which contained a discharge aperture, whereby the reactive force of the issuing jets of water rotated the tubes with the vessel and vertical shaft.

Scottish Turbine.—Closely allied to the preceding, but of a later and more elaborate construction, is the Scottish or Whitelaw turbine (*pl.* 65, *fig.* 1), which, however, originated with Mannoury d'Ectot (1807). It consists of an S-shaped tube (*A*) somewhat expanded in the centre, and connected with the vertical shaft by means of vertical rods. From below and into this central expansion of the S-tube (*A*) enters a close-fitting pipe (*B*), which introduces the water from a reservoir placed at a higher level. The tangential discharge of the water from both ends of the S-shaped tube rotates the wheel and shaft by the effect of the above-described reaction. The shaft is suspended from a spindle-block, which, to decrease frictional resistance, runs on rollers. By arranging several such S-shaped tubes and enlarging the central expansion, and at the same time abandoning the complete tangential outflow, there is formed a wheel-shaped body, which, being closely set with tubes, forms the transition to the early form of turbine, which consisted of two horizontal rims with vertically-curved vanes between them. Cadiat's turbine combines a wheel such as is above described, but which is so far imperfect that it allows the water only to flow in with a loss of impulsive force.

Fourneyron Turbine.—To overcome this imperfection, which was recognized before the erection of Cadiat's wheel, Fourneyron, in 1827, placed in the interior of the wheel a stationary deflecting apparatus called the "guide" or "directrix." In Figure 2, which represents a section in plan of both parts, that having the smaller diameter exhibits Fourneyron's guiding device, which is stationary, while that having the larger diameter is the revolving or turbine-wheel. The directrices, identified in the illustration by the heavy black lines, have a curvature opposite the curvature of the buckets of the turbine wheel, so that the water in passing from the guide into the turbine-wheel would, if the latter were stopped, be diverted in a sharp bend opposite to the direction given to it by the directrices of the guide.

Low-pressure Turbine.—Figure 4 exhibits Fourneyron's low-pressure turbine-wheel, and also represents a cross-section of the upper and lower water-channels. The turbine-wheel is connected with the shaft by means of a dish-like wheel composed of a system of radial arms, from which the water flows into the lower channel *D*. Into the interior of this wheel projects a cast-iron cylinder (cylindrical flume), which by means of a piston-like packing is tightly enclosed by a second cylinder. The inner cylinder can be raised or lowered between the turbine-wheel and the direc-

trix apparatus by the vertical rods seen in the Figure, so that the influx of the water can be partially or entirely shut off. The outer cylinder is tightly fixed in the wooden flooring *C*, so that the water passing (at *A*) into the upper chamber, which is completely enclosed by two brick channel-walls (*G*) and a wooden partition (*B*), can escape into the lower chamber *E* only through the wheel. The vertical cast-iron tube (seen in the centre of the picture) is likewise secured in a flooring above. It carries on its lower end the directrix apparatus, and encloses the shaft, which is provided with a cog-wheel on its upper projecting end, and the turbine-wheel on its lower end, supported by a pillow-block resting on a lever by which the wheel can be shifted vertically.

High-pressure Turbine.—The form of construction exhibited in Figure 3 (*pl.* 65) is Fourneyron's high-pressure turbine-wheel. It consists of a cast-iron cylindrical turbine chamber (*A*), provided with a securely-fitted cover, and rests upon the timber-work *D* over the lower water-channel. The influx of the water to the turbine chamber *A* is effected by means of a pipe (*B*) which extends to and is connected with the head-water channel or reservoir. The inflowing water, which would escape from the top of the cylinder were it not for the bolted cover, stands in the chamber *A* under high pressure, and hence the designation of "high-pressure" turbine in contradistinction to the low-pressure turbine above described. The shaft provided with the transmitting cog-wheel *G* and the rods of the cylindrical gate, which are moved by the crank and crank-shaft (*a*) by means of the gearing shown, pass through and are guided by stuffing-boxes in the cover of the turbine chamber.

In respect of a very small turbine erected at St. Blasien, according to Fourneyron's system, Redtenbacher reported that, notwithstanding its greatest diameter was only $12\frac{1}{4}$ inches and its inner diameter $7\frac{7}{8}$ inches, it produced an effect of forty-seven horse-power. Of course the height of fall of the water acting on the wheel was fully 108 metres (354 feet), while the current of water amounted to 115 feet per second, and the wheel had the enormous velocity of twenty-three hundred revolutions per minute. With such velocities, resulting from an excessive height of fall, the pivots are subjected to considerable wear. The main shaft and pivot are of steel, the wheel of wrought iron, and the other parts of cast iron.

Francis's Turbine.—Instead of placing a directrix apparatus in the interior of the turbine-wheel, as in the Fourneyron system, the reverse of this arrangement can be made. Constructions of this type are sometimes called Francis's turbines, after an American inventor who spent much time in experimentation in perfecting these turbines. They are also called American or "externally-moved" turbines, in contradistinction to the previously-described wheels, which are designated as "internally-moved" turbines. Various forms of Francis's turbines are shown on Plate 65 (*figs.* 5, 6) and Plate 66 (*figs.* 1–3), which, however, do not represent, in respect of external appearance and incidental details, Francis's original construction.

Figure 6 (*pl.* 65) exhibits a Francis turbine with many of its component parts omitted to give a view of its interior construction. The supply-pipe *A* is of rectangular cross-section; *B* is the turbine-wheel which is connected with the shaft *C* by the arms *c, c, c;* and *a, a, a* are the directrices to the paddles *D, D, D* of the turbine-wheel. The influx of the water is in the direction of the arrows in the tapering, spiral supply-pipe *A*, around and outside the guides; hence to this form of construction the term "spiral" turbine is sometimes applied. In Figure 5 the directrix apparatus is omitted, the influx of the water being directly to the wheel. The arrows indicate the direction of the inflowing water. The turbine-wheel *D* with its connecting arms *C, C* and shaft *A*, together with the bevel-gears, the transmitting shaft *B*, and pulley *I*, is readily distinguished. The prototype of Francis's turbine was an American invention called Howd's turbine, after its inventor, and was first used in the United States. It was simply constructed of wood and provided with straight directrices and turbine paddles. Figures 1 to 3 (*pl.* 66) show an improved construction of iron. Figure 1 is the directrix apparatus with straight paddles; Figure 2 is the turbine-wheel with curved paddles, and also the cover of the wheel-box or casing; and Figure 3 illustrates the manner in which the directrix is combined with the wheel-box.

Double Turbine.—Figure 4 (*pl.* 66) exhibits a double turbine, or the combination of a turbine moved from the exterior and one moved from the interior. The water, whose influx into the casing *C, C'* is at *C''*, passes into the directrices *D, D*, from the exterior, but reaches the lower turbine-wheel from the interior, by which arrangement it is possible to place the cylindrical gate *J* (shown partly cut away) on the exterior of the directrix apparatus. The rack-and-pinion rods *K, K* serve to raise and lower the cylindrical gate.

Henschel's Turbines.—While all the previously-described forms of construction may be deduced from Segner's reaction-wheel, Euler's wheel forms the original type of a system in which the paddles are arranged as shown in vertical section in Figure 6. The water does not here run horizontally, as in Figure 5, but vertically downward through the guides and turbine-wheel. Euler also was the first to introduce the guide-tubes or tube directrices, and, by a suitable construction of the wheel, to give to the water the above-mentioned vertical direction. The water, however, passes out nearly horizontally after moving over the vertical course. Euler's wheel was imperfectly constructed, because it consisted, like Segner's turbine, of separate curved tubes instead of a number of closely-placed channels, by which arrangement the wheel would have the form shown in Figure 7, which consists of two rims with curved paddles placed between them. The improved form of construction exhibited in the latter Figure is the only one used at the present time, and, according to Rühlmann's historical researches, was first introduced in 1837 by Henschel of Cassel, and not in 1840 by Fontaine, as claimed by the French. Fontaine can only lay claim to the invention of the

sluice (*pl.* 66, *fig.* 6), which admits of shutting off each separate tube or directrix.

The turbines represented on Plate 66 (*figs.* 7, 8) and Plate 67 (*figs.* 13, 14) are built according to Henschel's system, incorrectly called Fontaine's, and still more incorrectly Callon's system, which was invented still later. Figure 8 (*pl.* 66) is the most usual construction. The turbine casing with its supports (*B*) rests upon the foundation *A*. In the bottom of the water-chamber or timber wheel-box (shown in cross-section) is built, with a water-tight joint, the turbine casing enclosing the cast-iron guide or directrix apparatus (*F*). The latter consists of three circles or rings of directrices lying one within the other, but cast in one piece, each of which is similar in form to the turbine-wheel in Figure 7. Close beneath the directrix apparatus are three turbine-wheels, also cast in one piece, whose paddles, however, are curved in a direction opposite to those of the guide, of which arrangement Figure 6 is an example. The turbine-wheel is, of course, connected by a series of arms with the shaft, which passes, water-tight (at *R*), through the upper plate of the directrix apparatus. The shaft, however, consists of a tube which is suspended from the top by means of a bearing, and extends from the foundation to the bevel gear-wheel *K*, which drives the bevel-wheel *L*. The internal ring of the triple-guide is provided with clack-valves, and the central ring with a cylindrical gate (*N*), which can be moved by the rack and gear mechanism *O*, *P*, *S*, *Q*. The external ring always remains open, while the two interior rings are opened as required, either for greater effect or on account of le[ss] supply of water. The direction of the influx of the water to the wheel-box, and that of its efflux through the lower channel, are indicated by the arrows.

Figure 14 (*pl.* 67) represents a form of construction similar to the preceding, with the exception of an iron water-chamber for the wheel. In front is seen the throttle or admission-gate *A* in the influx of the wheel-box, and by the removal of one of its sides (*B*) a view of the directrix apparatus is obtained. The wheel-casing, as in Figure 3 (*pl.* 65), is closed by a cover which is provided with a stuffing-box for packing the shaft passing through it, and this arrangement, for the same reason given in describing the latter figure, is a high-pressure turbine. In Figure 13 (*pl.* 67) there is no directrix apparatus, the turbine-wheel (*pl.* 66, *fig.* 7) being placed immediately under the helical influx casing, from which the rather meaningless term "helix" turbine has been applied to this construction.

Henschel's construction gave rise also to the invention of turbines with long helical paddles or with wheels consisting of a screw (*pl.* 67, *fig.* 12). A prominent feature of Henschel's invention, however, is the draft-tube, an extension of the casing or discharge-tube into the tail water, which has been claimed by French writers to be the invention of one of their countrymen, and to which the term "Jonval" turbine has been applied, as also to an entire system of turbine-wheels.

Henschel-Jonval High-pressure Turbine.—Figure 15 (*pl.* 67) gives an illustration of the extended casing or tube of the Henschel-Jonval system. Two high-pressure turbines (twin turbines) stand beside each other and act conjointly upon the central transmitting shaft at the top by means of spur-wheels on the upper ends of the turbine-shafts which project through stuffing-boxes in the covers of the wheel-cases. The influx pipes are indicated by the two black circles, and immediately below these in the casing are the guides and turbine-wheels, whose casings extend to the lower channel, forming an air-tube extending to and under the surface of the tail-water. Jonval, in taking out a patent for such a turbine in 1841, four years later than Henschel, and at a time when one of Henschel's twin turbines was actually driving a stone-polishing establishment at Minden in the duchy of Brunswick, called his construction a "double-effect" turbine. This designation may be said to be correct, inasmuch as such turbines act by suction as well as by pressure, since the effect is produced by the water in the tube beneath the wheel as well as by that standing above it.

Geyelin-Jonval Turbines.—The three Geyelin-Jonval turbines at the Philadelphia waterworks, shown in Figure 6 (*pl.* 69), are each 10¼ feet in diameter, with sixty blades in the movable wheels, and are the largest of their kind in America. They are of the Jonval system—that is, they receive the water on the top, where it is directed by guides and discharged downward into draught tubes. At the bottom end of each tube there is a controlling gate in the form of a cylinder, which is made to rise or lower as the power is needed for driving the pumps. The movable wheels are placed on vertical shafts, which were originally supported on lignum-vitæ steps, but these have in part been replaced by glass suspension-boxes (*figs.* 3, 4), which were found better to answer the purpose of supporting the weight of the water and the machinery (which is calculated to amount to 30,000 pounds) than the lignum-vitæ steps. The suspension-boxes are secured to the top of the inlet-casing. These turbines were constructed to force to a height of 125 feet 8,000,000 gallons of water every twenty-four hours, with a fall of 8 feet. This work they regularly perform even with a reduced fall. The fall varies with the tides from 5 feet to 13 feet; when at its maximum the turbines are to a great extent closed, so as to check their power. With the view of maintaining a fair percentage of effectiveness of the water in all conditions of the fall, one of the turbines is arranged with a division in both the movable and the guide wheel: by means of this division one-third of the water can be shut off. Each of the three turbines is connected, by means of a pair of bevel and a pair of spur-mortise gears, to two horizontal double-acting piston-pumps of 22 inches diameter and 6 feet stroke.

Figure 1 represents an American improved Jonval turbine with double hood-gates placed immediately over the guide-wheel, which arrangement has several advantages over other forms of gates. Figure 2 exhibits an American duplex turbine of the Jonval sytem. This turbine is divided into two unequal compartments, each having its own gate and independ-

ent gate-motion. This form of turbine has the advantage of being compact and of using economically while in motion—that is, without stopping the machinery operated—one-third, one-half, or two-thirds the water the turbine is capable of absorbing.

The Leffel Double Turbine (*pl.* 66, *figs.* 9, 10) has a combination of two independent sets and kinds of buckets, one a vertical, the other a central discharge, each set being entirely unlike the other in its principle of action upon the water, yet each wheel or series of buckets receiving its water from the same set of guides at the same time; but the water is acted upon only once, since half the water admitted by the guides passes to one wheel and the other half of the water to the other wheel, the water being nicely separated and divided by the partition or diaphragm between the two wheels, and leaving both wheels or sets of buckets at the same time and as quickly as possible. These two sets of buckets are so combined as to make really but one wheel—that is, both are cast in one piece and placed upon the same shaft. Figure 10 exhibits the general appearance of the wheel ready for attachment of the shaft above it.

Girard's Turbines.—As examples of novel arrangement in the construction of turbines, we give Girard's "siphon" turbine and "hydro-pneumatic" turbine, represented in Figures 1 and 2 (*pl.* 68). The internal structure of the former, except its hydro-pneumatization, corresponds with that of the latter. The object of the siphon-shaped supply-pipe is to permit the water to pass into the wheel free from the rapid circular motion which occurs notwithstanding there may be a very small height of fall. Hydro-pneumatization consists in pumping air by means of a pump suspended in the wheel into a receiver (*fig.* 2), which is formed by the hermetically-closed casing of the turbine-wheel, the object being to force the level of the water below the wheel, which otherwise would be submerged in the tail-water and its motion impeded by reason of the frictional resistance therein. What is still more essential is to overcome a phenomenon (*pl.* 66, *figs.* 5, 6) which has the tendency to decrease the effect. It will be seen that in case the single sluice or flume of the previously-described constructions is partially lowered, the water passes through the spaces of the paddle-wheel in a turbulent state accompanied by rapid circular motion and consequent loss of effect. These rapid rotations can be controlled by passing compressed air from the pneumatized casing into the spaces of the paddle-wheel by means of apertures in the latter, as seen in Figure 6. Moreover, by pneumatization, those losses of effect which originate by the tail-water penetrating the empty paddle-spaces are suppressed in their incipiency.

Partial Turbine and Tangential Wheels.—Figure 3 (*pl.* 68) represents in cross-section a tangential wheel or partial turbine. It consists of two wheels constructed according to Girard's system, which are struck by the flowing water at their lowest point. This illustration exhibits an example of a double turbine and also one with a vertical position of the wheel, consequently with the shaft arranged horizontally.

The vertical wheel exhibited in Figure 4 (*pl.* 68) is intended particularly for mining purposes and for small wheels under high heads where gearing is not only difficult to arrange and to keep in order, but is also frequently impracticable otherwise. The horizontal shaft of the water-wheel, on which is placed a pulley, affords not only the simplest, but also the most efficient, means of connecting the power to the point where it is desired to be used. This is easily effected, and any desirable amount of power may be transmitted and motion obtained by properly proportioned pulleys with light but sufficient belting.

Figure 7 (*pl.* 65) illustrates a primitive form of water-wheel on the principle of a turbine. The current of water from the spout falls upon spoon-shaped radiating paddles, which are so set in the shaft that the side-wise action of the falling water forces the paddles around and rotates the shaft. This construction is called a "spoon-wheel," and when surrounded by a cylindrical curb it is termed a "tub-wheel." The effect of such a wheel has been improved by projecting the current on the wheel tangentially, as is shown in the Algerian mill on Plate 3 (*fig.* 3), and further improved in the Pelton wheel represented on Plate 64 (*fig.* 1). A wheel similar to the spoon-wheel is employed in driving the Turkish mill shown on Plate 3 (*fig.* 5).

Constructive Details.—Of special importance for the effectiveness of turbines is the construction of the pivots. Horizontal shafts can readily be provided with the usual bearings which are not exposed to unfavorable effects, but with most turbines having vertical shafts the pivots must run under water, where they are subjected to rapid wear, especially if inaccessible, by the percolation of the sand carried by the water into their sockets. To protect them in the latter respect, as also to admit of the application of lubricating oil and to effect their accurate vertical position, many widely-differing forms of construction and internal arrangements have been given to them, examples of which are exhibited in Figures 1 to 4 and 7 to 10 (*pl.* 67). There are also mechanical devices by which the pivot is relieved from these causes of wear by being extended above the water (*pl.* 65, *figs.* 1, 4; *pl.* 66, *figs.* 7, 8; *pl.* 67, *fig.* 3; *pl.* 68, *fig.* 1). Figures 5 and 6 (*pl.* 67) especially represent, in cross-section, such an arrangement of the pivot, in which a hollow turbine-shaft and a stationary pivot-spindle reaching from the tail-water to the head-water are used. Figure 4 (*pl.* 67) also shows such a construction. Figures 9 and 10 exhibit in plan and sectional elevation a pivot with three anti-friction wheels arranged above the water for decreasing frictional resistance.

Figures 3 and 4 (*pl.* 69) show, in vertical section and in plan, a glass suspension-box designed to replace the "step" bearing of turbines. It is composed of a circular disc, which is fastened to the inlet-casing, and in whose depressed portion are arranged stationary glass segments (*B*); the space around each segment allows a free circulation of the lubricant with which it is filled. On the glass segments revolves a metal ring (*A*) which is firmly secured to the turbine shaft.

III. AËRO-DYNAMIC MOTORS.

1. Wind-wheels.

The wind-wheel was first utilized as a source of motive power by the Germans during the eleventh century. The oldest form of windmill was doubtless that of the "post"-mill, in which the whole structure was carried on a post set in the ground and rotated by a long lever (*pl.* 3, *fig.* 8). The post-mill was succeeded by the tower- or Holland mill (*fig.* 7), a structure which consisted of a stationary tower, the wind-shaft and sails being carried on a revolving cap at the top. Tower-mills are largely employed in Holland for drainage purposes. Our present subject, however, is not specifically *windmills*, but *wind-wheels* in general, as applied for the obtainment of motive power. Wind-wheels, from their mode of action, are of two classes—(1) those rotating *vertically* on horizontal axes, and (2) those rotating *horizontally* on vertical axes.

Vertical Wind-wheels: Vanes or Sails.—In the ordinary early form of windmill the wheel consists of planes combined with and placed at right angles to a shaft, which is revolved by the impactive force of the wind acting on the planes. These planes are called "vanes" or "sails," a number of which—generally four or five, though exceptionally three, six, or even twelve—are connected with the head of the axle or shaft, which is set horizontally or inclined to the horizon at an angle of from 8° to 15°. Each of these vanes, or "whips," as they are sometimes called, usually from 30 to 40 feet in length, is composed of a long tapering bar of wood with short cross-pieces or rungs, whose extremities are connected with one another by wooden strips. This frame is covered with sail-cloth or with thin boards. By an inclination of the rungs obliquely to the geometrical plane of the whips the sails receive an inclination in the direction of the wind blowing parallel to the axle, in consequence of which the wheel is rotated. Without this inclination the wind would impart to the wheel a pressure only in the line of its axis, but with it the impactive force of the wind is divided into a component of a power directed in a line parallel and normal to the surface of the vane; hence, while in the first case the wind exerts an axial pressure only, in the latter it effects a rotation. The inclination of the axis referred to above is given for a similar reason, it having been found from experience that the direction of the wind is somewhat downward, generally forming, in open countries, an angle of about 18° with the surface of the ground.

In the earlier wheels the same inclination was given to all the rungs, but in modern constructions it is less for the rungs at the greatest distance from the axle, the lower part forming with the axis an angle of about 60°, and the upper of about 80°, in consequence of which the covering of the vanes forms an oblique and somewhat winding surface, with their concavities facing the wind. The inclination of the rungs being the basis of a suitable construction, and their difference of inclination being conducive to a winding surface, which is an improvement, the best form of construc-

tion results from further bending the surface and making it concave by a curvature of the whip itself.

Figure 1 (*pl.* 70) gives an illustration of the upper portion of a tower-mill. *A* is the tower, which, for containing the machinery driven by the vertical shaft *L*, may be constructed of wood or of masonry; *B* is the tower-cap, which is movable in a horizontal plane; *CDE* is the axle of the wheel; *F*, *F* are the whips, composed of two parts, and *FG* is a cable, which is secured to *E* at *G* for the support of the outer ends of each whip. On the axle of the wind-wheel there is secured a cog-wheel, which gears into a like wheel, of smaller diameter, upon a vertical shaft placed centrally in the mill, so that the vane-wheel and the cap of the tower, when revolving to face the wind from another quarter, may continue in gear therewith, and in all positions may communicate motion to the mill-machinery, which is located about the lower end of this shaft.

Wind-wheel Power.—The following table illustrates the power which is guaranteed by manufacturers, and which has been attained by hundreds of wind-wheels in the United States and elsewhere. "The actual results tabulated are in close agreement which those obtained by theoretical analysis of the impulse of wind upon windmill-blades" (Wolff).

Diameter of Wheel.	Velocity of wind, in miles per hour	Revolutions of wheel per minute.	Gallons of water raised per minute to an elevation of						Equivalent actual horse-power.	Average number of hours per day.
			25 feet.	50 feet.	75 feet.	100 feet.	150 feet.	200 feet.		
8½ feet	16	70–75	6.162	3.016	. . .	. . .	. . .	. . .	0.04	8
10 "	16	60–65	19.179	9.563	6.638	4.750	. . .	. . .	0.12	8
12 "	16	55–60	33.941	17.952	11.851	8.485	5.680	. . .	0.21	8
14 "	16	50–55	45.139	22.569	15.304	11.246	7 807	4.998	0.28	8
16 "	16	45–50	64.000	31.654	19.542	16.150	9.771	8.075	0.41	8
18 "	16	40–45	97.682	52.165	32.513	24.421	17.485	12.211	0.61	8
20 "	16	35–40	124.950	63.750	40.800	31.248	19.284	15.938	0.78	8
25 "	16	30–35	212.381	106.964	71.604	49.725	37.349	26.741	1.34	8

Regulation of the Wheel.—To accommodate the mill to the variations in the direction of the wind the frame or a portion of the tower carrying the wheel, in the ordinary form of construction, turns around in a horizontal plane on a fixed vertical axis. If, on account of the strength of the wind, it is necessary to check the rapidity of the wheel, a portion of the vane-covering is removed; this regulation of the wheel is in conformity with rules derived from experience with wind-mills, and varies with each type. In more modern constructions the regulation of the wheel is frequently attained by altering the angle at which the sails are presented; this is done by turning the vanes on their whips, by which adjustment, however, the previously mentioned influential inclination of the surfaces of the vanes is changed. Andrew Meikle of Scotland in 1772 invented a plan for automatically adjusting the area of the sails to the force of the wind, and Bywater of Nottingham, England, in 1804 patented a method of rolling up the sails for adjusting them in like manner by means of a

weighted lever. Sir W. Cubitt in 1807 introduced automatic reefing arrangements. The sails were made of thin boards or pivoted slats like those of a Venetian blind, and were held up to the wind by a counteracting weight; as the strength of the wind increased the slats were pressed back, by which action they exposed less surface to the wind.

Self-acting Regulation of the Wheel.—From an economical standpoint it is important that both the above changes should be effected by utilizing the force of the wind itself; efforts have consequently been directed toward making these constructions self-acting. It is stated that the first method adopted to present the vanes to the wind was to float the mill and turn it in the water as occasion required. The next was to put the mill on a post and turn it on this axis; this was called the "German system." Subsequently the cap or roof of the mill was made to revolve by means of a vane of considerable area attached to the movable framework; this was a Dutch invention of the sixteenth century. Meikle in 1750 introduced an auxiliary windmill or fan, placed at right angles to the principal wheel, for automatically turning the face to the wind. When the wind shifted, the small fan began to revolve and by an actuating gear rotated the cap of the mill. Our illustrations exhibit various forms of the self-acting setting of the wind-shaft, both on the principle of a large vane of wood, sail-cloth, or sheet-iron, and on that of a small wheel acting on a mechanism which rotates the upper portion of the frame or tower. The self-acting change of the surfaces and of the inclination of the vanes is effected by numerous devices, a few of which will be described.

Trull's Wind-wheel.—Figure 6 (*pl.* 70) shows the Trull wind-wheel, which turns on a plate placed on the top of a frame (*A*) and is rotated to face the wind by a large vane set horizontally to the plane of the wheel. The four sails can be turned (as shown in Figure 5 on an enlarged scale) by segments of cog-wheels on the lower ends of the whips. These cog-wheels engage with a square rod, toothed on its four sides, which lies in the hollow wheel-shaft and is movable in the axis of the shaft. This rack-rod connects with a mechanism which is moved by a ball-governor placed on the vertical shaft, near the foot of the frame. The faster the wheel rotates with an increasing wind or a decreasing resistance of the operating machines, the more rapidly the vertical shaft *I*, connected with the wheel-shaft by cog-wheels, is revolved; and the farther the balls of the governor are centrifugally forced apart, the flatter the vanes are set by means of the rack-mechanism. The rotation of the wheel being thus retarded by the flattening of the vanes, its velocity will remain quite constant with every change in the force of the wind; and if the inclination of the sails is regulated for a minimum velocity of the wind for a degree of effect as advantageous as possible, the power developed will assume the desired strength in all the variations. The dropping of the lever *K* completely flattens the vanes and stops the wheel. The transmission of the motion and power to a mill, pump, or other machine is effected by means of a pulley or a cog-wheel usually provided.

The Brewster Wind-wheel (*pl.* 70, *fig.* 2) exhibits another form of construction in which the wind effects the setting of the vanes by means of a bar in a hollow shaft. This bar (E), however, is not toothed, as in the preceding device; but to attain the same object it carries on its outer end cross-bars (F), to whose points and thence to one corner of each vane cords (G) are fastened. While the force of the wind acting on the sails A tends to shift or to press in the bar E in the direction indicated by the arrow, a curved movable bar (H) opposes this action by being pressed against the bar E by the weight J. The adjustment caused by this action and counteraction of the bar insures the proper inclination of the vane-surfaces, corresponding to the force of the prevailing wind. The mechanism of the small wheel effects the setting of the large wheel in the direction of the wind, and the face-gear D, K transmits the power to the vertical shaft.

Kirchweger's Wind-wheel, shown in vertical cross-section in Figure 7, is constructed entirely of sheet iron, and is provided with a regulating device similar to the wheel in Figure 2. The illustration represents one of the sails in its edgewise position to the wind, and also the hollow shaft enclosing the shiftable bar which acts at the back of the mill against a lever and is provided at its outer end with a five-armed cross. To the left (in the cut) is given a front view of the cast-iron hub, which is connected with the wheel-shaft and serves to fasten the five whips of the vanes, as also the cross in front of it. This form of wind-wheel is successfully employed for water-stations on many Hanoverian railways.

Witting's Wind-wheel (*fig.* 4) is supported by a frame (A) and rests upon a ring (D), which is rotated on rolls in the journals a. The wheel is adjusted by a bar (D), which is shiftable in the hollow shaft c. The bar bears with its inner end (*fig.* 3 in plan) against a socket (l), held by the cords or chains f, the pulleys F, and the weights G. The vanes are turned on their whips by a rack-mechanism placed on the outer end of the bar. The sails H can be furled or unfurled on the rollers h, h by the pulleys u fastened on them, and the cords m, r, as also by the blocks q, s.

Cubitt's Wind-wheel, of which Figure 1 (*pl.* 71) illustrates the central portions of two sails, has in a hollow shaft a movable bar which serves also as the principal regulating mechanism. In this wheel the vane-covering, however, does not consist of wood or of sail-cloth, but of a kind of sheet-iron Venetian blind; so that, instead of a twisting of the entire vane-surface on its whip with a change in the force of the wind, a shifting of the separate component parts of the blind is effected. The tendency of the increasing pressure of the wind is to impart to the levers B, K, L, by means of the racks L, the position indicated by the dotted lines, but at the same time the weight G, suspended to a cord or chain (F) and wound around the drum, counteracts this movement by the small cog-wheel on the drum-shaft actuating the rack D on the shiftable bar C, thus effecting an adjustment for every variation of the wind.

Brown's Wind-wheel.—In place of the shiftable bar in a hollow shaft,

Dr. Frank, Johnson, Brown, and Lempeke have used for their wind-wheels the mechanism shown in Figures 8 and 9 (*pl.* 70) and Figures 2, 3, 7, and 9 (*pl.* 71), described as follows: In Brown's wind-wheel (*pl.* 71, *fig.* 3) the rods *G*, *M* are connected by loose joints to a hub, which is movable on the wheel-shaft. The rods are also attached to the whips by socket-joints (*H*), in which the whips can move. By this mechanism the increasing pressure of the wind tends to slide the hub along the shaft, but in so doing has to overcome the resistance of the weight *P* suspended to the lever *O*, as also that of a spiral spring placed between the hub and a socket connected with the wheel-shaft. The momentary acceleration of the rotation of the wheel caused by an increased force of the wind impels the sails *H* radially outward by the centrifugal action of the heavy bearings *L* (shown on an enlarged scale in Figure 2), and thus, by means of the helical groove *L*, turns the vane-surface and effects a change in the angle of incidence. The wheel, as shown in the Figure, is set face to the wind by the large vane *B* connected with the frame. The transmitting mechanism is represented enlarged in Figure 4.

Dr. Frank's and Johnson's Wind-wheels.—While in Figure 6 (*pl.* 70) the regulation of the angle of incidence is effected, with the assistance of centrifugal force, by the ball-governor, and in Figures 2 and 3 (*pl.* 71) by a weight (*L*) provided with a spiral groove, the principle applied in the wheels (*pl.* 70, *figs.* 8, 9; *pl.* 71, *fig.* 7) constructed by Dr. Frank and Johnson is that of weights, one of which is designated by *c* in Figure 7 (*pl.* 71). It is shiftable on the bar *c*, *c*, and is held in a certain position by a spiral spring secured to the bar. To the weight are fastened the rods *r*, laterally connected with three vanes, which can be turned on their whips. An acceleration of the speed of the wheel forces the weights radially outward as far as the spiral springs will permit, and by the connection of the rods causes the turning and consequent flattening of the vanes. The portion of the frame moved by the large vane is rotated on a hollow axis supported by the fixed frame and pivoted on the ring *S*, which is connected with the horizontal portion of the revolving frame by an oblique stay and a vertical rod (*B*). Through the hollow axis passes the vertical driving-shaft, which engages, by means of bevel-gears, with the wheel-shaft, and carries on its lower end the pulley-wheel *V* for the transmission of the motion and power to the working machines. Besides being secured to the vanes, the centrifugal weights are also connected with levers (*pl.* 70, *fig.* 9), which, by acting upon a brake-wheel, bring the wind-wheel to a stand-still. Figure 8, of which Figure 9 is a front view of the wheel, represents a construction which differs from Figure 7 (*pl.* 71) only in having a lighter frame and in being provided with a vane covered with sail-cloth.

Lempeke's Wind-wheel.—On the vane-shaft in Lempeke's wind-wheel (*fig.* 9) there is a movable collar, which is connected with the vanes at their outer ends by chains, and by means of horizontal and vertical drawing-rods with another movable collar, which encloses the vertical support and is connected by a chain to a weighted lever suspended from

it. As the vanes are fastened to the whips, and as the latter are elastic, there is produced by the described mechanism, through the elastic whips, the loaded lever, and the force of the wind, an inclination of the sails suited to every velocity of the wind. Moreover, it may be noted that the shiftable collar on the vane-shaft acts at the same time on a lever-mechanism which effects an automatic breaking, while the fork-like lever placed below it admits of a breaking by hand. The vertical driving-shaft is enclosed by a hollow cast-iron column, which is supported by an encircling ring attached to the four brace-irons firmly secured by screws to the fixed wooden frame. The wheel is turned to the wind. by a vane (not shown in the illustration).

American Self-regulating Wind-wheels.—The self-regulating principle of American windmills differs essentially from that of the above-described European mills. Figure 6 (*pl.* 71) exhibits a self-acting wheel which has the proper amount of speed in ordinary winds; but if the current is too strong, the wheel is forced partially around toward the rudder, in which position it continues to work at a regular speed, and automatically returns to its normal position when the force of the wind abates. If, however, the velocity of the wind becomes very great, the wheel is folded around by the side of and parallel to the rudder, thus presenting the edge of the wheel to the wind, where it remains at rest until the wind-storm ceases, when it again resumes its position face to the wind. The wheel can be stopped at any time by means of the weighted gear-lever, to which is attached a wire passing down through the centre of the turn-table and swivel and attached to a lever at the bottom of the tower. By simply releasing the lower lever the weighted lever brings the wheel again into position, ready for working. The operating mechanism of the mill is fastened to the frame or tower by an iron cap covering the upper ends of the timbers, to which it is strongly secured. The wind-shaft carries on its inner end a crank-wheel, which operates a curved bar attached to a connecting-rod.

Twist-slat Wind-wheels.—There are two general classes of American wheels, which are known as the "open wheel" and the "solid wheel." The former is so constructed that each section tilts or turns separately, while in the latter the entire wheel is solidly put together, with the sections immovable. Of the latter type, Figure 8 exhibits a twist-slat wheel which has radiating fans or slats set in double rims, and is so constructed that their slant or pitch varies from the centre to the circumference. As the circumference of a wheel travels a greater distance, and consequently faster, than the parts nearer its centre, the flatter the fans or sails are laid at this point the less resistance there is to the rotation of the wheel; and by giving the slats a longitudinal twist nearly uniform width of slats may be used, which gives to the wheel the greatest surface-area for receiving the impulse of the wind.

The "Wind-engine," so called (*fig.* 5), is constructed on the turbine principle, which is that a current of water in its descent will follow a curved surface and reach a given horizontal plane in the same time that it

would take to pass over a gravitating curve, although the actual distance of the former curve should be much greater than that of the latter. In accordance with this principle, the wind does not lose its force on its first contact with the buckets of the wind-wheel, but, like the current of water following a curve, continues its impulse until it escapes from the peripheries of the buckets. The latter, which are made of smooth, solid iron, are firmly bolted to the flattened ends of iron pipes, which form the spokes of the wheel and are laterally and diagonally stiffened by tie-rods. The hub is fitted and secured to the shaft by set-screws and bolts. The vane-socket is hinged to the turn-table, which is connected by a rod with an eccentric attached to the turn-table by a vertical bar. The leverage obtained by the vane through the peculiar arrangement of the eccentric holds the wheel to the wind; and when the wind, by reason of its extra pressure during a storm, forces or shifts the wheel around parallel with the vane, the leverage brings it again into position, thus making the engine entirely self-regulating. There is also provided a brake, which prevents the revolution of the wheel when "out of wind." The power is transmitted from the main shaft by a crank-wheel and a connecting-rod combined with a bent lever, which is connected with the vertical rod.

The Challenge Windmill (*pl.* 72, *figs.* 1, 2) differs from all others in that it has two power wind-wheels and two small wheels that operate a screw which keeps the faces of the power-wheels perfectly to the wind at all times. The two power-wheels are connected with separate shafts, both in the same line, and turn in opposite directions, carrying the main driving-gear at the end of each shaft, which centres the turn-table. These gears engage a centre pinion in the turn-table, communicating the power of each wheel to opposite sides of the pinion, thereby driving it in the same direction. From this point the common system of shafts, pulleys, and belts is brought into use to reach the machinery to be driven. The two small wheels on each side of the power-wheels are attached to one shaft, transversely to the power-wheel shafts, and both aid in operating a screw or worm, which engages a segment that encircles the chair or bed-plate upon which the turn-table, with all the mechanism, rests. When the wind radiates from a line parallel to the face of these wheels, it acts upon them, and they revolve until the screw traverses the circle segment sufficiently to bring the wheels into line with the wind; when this is accomplished, they rest. The power-wheels are then at a perfect right angle to the wind, and they cannot change from that position except by a change of wind to act upon the side wheels. The mechanical construction of this wheel is such that uniformity of power and of speed is maintained in all degrees of wind above the minimum by the adjustment of a weight upon a lever in reach of the operator, the power being commensurate to the resistance of the weight according to its adjustment on the lever.

Horizontal Wheels.—The construction of the wind-wheels thus far described exhibits on comparative review a similarity to that of certain transport machines for water and for air; they may also be compared with

several makes of centrifugal pumps and with a few forms of ventilators, of which, for example, that shown in Figure 7 (*pl.* 118) has vanes like those of a wind-wheel. Certain other motive machines also resemble wind-wheels. The turbine-wheel of Henschel's system (*pl.* 66, *fig.* 6) consists of a number of oblique or helically-curved blades grouped around a shaft in the form of a wind-wheel. These surfaces form the principal constituents of the wind-wheel as of the turbine, they being in the first the receivers of the motive substance air, and in the latter of water.

It is natural that such comparisons should suggest the idea of other forms of constructions for aëro-dynamic purposes. To these belongs the so-called "Francis turbine" (*pl.* 65, *fig.* 6), which is moved by the water acting on the periphery of the wheel. If the casing of this turbine were removed, so that only the guide-wheel and the turbine-wheel remained, we should have nearly the form which has been, and still is occasionally, employed in the construction of windmills. The wheel-shaft, as in the turbine, is placed vertically—an arrangement which obviates the necessity of setting the wheel in the direction of the wind and of employing the vane and its auxiliary mechanism. From whatever direction the wind may come, it strikes one half the wheel; so that in any case the directrix upon one-fourth of the wheel transmits the wind-power to the turbine, while the directrix upon the other fourth deflects the wind and prevents it from exerting an opposing influence upon the rotation of the wheel. Wheels with vertical shafts are called "horizontal" wind-wheels, because they rotate in a horizontal plane.

Field's Horizontal Wind-wheel.—Figures 3 and 4 (*pl.* 72) exhibit two forms of horizontal wheels. In Field's horizontal wind-wheel (*fig.* 4) the whips or wheel-arms *E*, which are fastened on the vertical shaft *B* by means of a hub (*D*), are supported by the connecting-rods *g* secured to the vertical shaft and are stiffened by the rods *h*. The arms carry on their extremities four frames (*F*), which form the bearings for the cranked shafts *i*, and to the latter the vanes *G* are attached. If these frames were simply covered with sail-cloth, it is evident that the wind would strike those vane-surfaces which in the course of their rotation must move against it as forcibly as it would strike those surfaces which the wind is to move, and in consequence the wheel would come to a stand. A mechanism must, therefore, be provided which will so operate that the vanes to be moved in the direction of the wind will present their full planes to its force, and that the vanes moving in the opposite direction will present as small surfaces as possible. Such a mechanism is formed by the cords *l*, which are loaded with the weights *W* and conducted from below the hub *D*, along the under side of the whips, over the pulleys on the outer ends of the oblique arms and attached to the cranks of the vanes *G*. As these revolve, the wind, acting on their broad sides, lays the vanes flat against their frames (thus raising the weights), where they are held by and exposed to the full force of the wind. On moving farther the vanes are swung around by means of the weighted cords so as to feather or present their edges until

they again come into position in the direction of the wind. By means of a hand spider-wheel (*M*) the weights *W* can be lifted, whereby the cords are relaxed, the vanes are liberated, and the wheel is brought to a stand. The construction shown in the Figure is evidently simpler than the vertical wind-wheel, as both the mechanism of the wind-vane and the bevel-gear connection of the horizontal and vertical shafts are omitted, the wind-wheel being directly connected with the vertical driving-shaft, which for the transmission of the power needs only to be provided, on its lower end, with a cog-wheel (*C*) or a pulley or a crank, as may be needed.

Goodwin-Hawkins Horizontal Wind-wheel.—The simplest form of wind-wheel is perhaps the construction of the Goodwin Hawkins wheel, shown in Figure 3 (*pl.* 72), in which the adjusting mechanism is also omitted. In a hollow column (*A*) is placed the shaft *B*, which by means of arms carries six hollow cones of metal. These by aëro-dynamic or hydraulic law possess the property of receiving a greater impetus from the wind striking their concavities than from its acting on their convex surfaces; hence, with a current of wind in the direction from right to left, parallel to the plane of the illustration, the cone *C* nearest the observer is more forcibly affected by the impulse of the wind than the cone on the opposite side, and from the difference in these forces the rotation of the wheel is accomplished. Even if the wheel be provided with a mechanism to regulate the varying velocity of rotation, which, as in this case, where a pump is to be driven, is regulated by the height of the water in the reservoir *J*, the construction of this horizontal wheel is simpler than that of a vertical wheel. The reason that wheels of this form are not preferred is because with an equal size they are less affected by the wind than vertical wheels—in other words, they must for the performance of a certain desired effect be larger than the latter—and hence, notwithstanding their simplicity, they are more expensive under otherwise equal conditions than vertical wheels for the same purposes.

The Wind Turbine-wheel (*figs.* 5, 6), which is of American make, rotates in a horizontal plane. In Figure 5, *A* represents the outside shutters which surround the wheel, a portion of which is cut away to show the perpendicular fans, *B*. These shutters, each of which rests upon a pivot, are concave on the inner side, and all are so connected at the top as to admit of being opened and closed like the slat of a blind. Below is the walking-beam *C*, with pitman and crank connected. The crank is fastened to the bottom of the wheel by a cast flange or by a shaft running entirely through the middle to the top of the wheel, and rests upon a hardened-steel step or bearing. Instead of employing a crank motion for running the machinery, the power may be obtained by gearing directly to the shaft at the bottom of the wheel. The rope seen at the right is attached to the shutters, and when weighted acts automatically with them in regulating the supply of wind to the wheel. The action of the wind upon the wheel is shown in the sectional view given in Figure 6, in which *s s s* represent sixteen outside shutters that open to admit the wind

and close to shut it off; *fff* show the sixteen fans of the wheel upon which the wind acts. (The arrows denote the direction of the wind in passing through the wheel.) Thus it is seen that the wind acts upon almost every part of the wheel at the same time, and nearly as great an impulse is given to the wheel as the wind strikes the fans in coming out of it as is given when the wind goes into it.

For the same reason that the question of cost is an important factor in the practical value of a motive machine, wind-wheels have been unable to compete with most other motors, notwithstanding the facts that wind is free and that running expenses are small in comparison with those for thermo-dynamic, or even hydraulic, motors. Yet they might be more generally employed if, in the majority of cases where they could be applied, it were not for the financial and technical disadvantages imposed by the uncertainty of the wind and the consequent interruption to the working machine. Wind-wheels are not very powerful motors, and in their working they are variable and intermittent; in good situations they will generally work, on an average, about one-third of the time. Small wind-wheels are useful on farms for grinding grain, sawing wood, and pumping water, for which latter purpose they are also largely employed at watering-stations on American railways.

IV. THERMO-DYNAMIC MOTORS.

1. STEAM-BOILERS.

A steam-boiler is a mechanical arrangement in which heat, evolved by the combustion of fuel, is absorbed by a liquid (generally water), whose tension is thereby increased. When used in connection with a steam-engine, the water is converted into steam, whose tension is used to produce mechanical motion by impelling a piston. Water is always converted into steam in boilers used for motive power, but not always in boilers used for heating purposes; it is with the former only that we shall deal here. The word "generator" would be more appropriate than "boiler," as any pot or kettle may constitute a boiler.

Classification and Construction.—Boilers are made of cast iron, wrought iron, and steel, and, for special purposes, small portions of them are made of sheet copper. They may be classified as spherical, cylindrical, egg-shaped, wagon-top, haystack, etc. One of the earliest forms was spherical, the fire being underneath, and this was followed by a flat-bottomed, curved-topped cylinder surrounded with mason-work flues. Boilers are generally cylindrical or are made up of cylinders and cylindrical tubes, although there are varieties principally composed of small spheres suitably joined. Other forms, as the wagon-top, haystack, etc., have been abandoned, the cylinder and the sphere being chosen for their simplicity of construction, and for the reason that those shapes best resist deformation from internal pressure.

Plain Cylindrical Boiler.—The simplest type is the plain cylinder so set in brickwork as to receive the furnace-heat only upon its lower surfaces. A development of this is so set as to give the gases of combustion passage first under the cylindrical "shell" from front to back, then along one side from back to front, then along the other side from front to back, where they are allowed to pass into the chimney or stack or into a flue leading thereto. In all these forms the boiler proper is a plain cylinder merely supplied with the necessary man-holes and hand-holes for inspection, cleaning, and repair, with an inlet for water and an outlet for steam, and with fittings and attachments designed to increase safety and convenience.

Internally-fired Boilers.—A development of the plain cylinder in the direction of complexity has the entire length of the cylindrical shell from head to head a large cylindrical passage or flue, in which is the grate and through which the gases of combustion pass from front to back, next along the outside from back to front, and then underneath from front to back. This is called a "Cornish boiler" (*pl.* 73, *fig.* 4). A modification of this (the "Lancashire," *figs.* 7, 8) has two lengthwise and parallel cylindrical flues, with a grate in each, in which flues the gases of combustion take a course somewhat similar to that taken by those in the Cornish boiler. One advantage of the Cornish and Lancashire types is that they may be

set up without brick-work. Boilers in which the grate is contained in the flue or flues are called "internally-fired" boilers, of which the Galloway (*pl.* 73, *figs.* 11, 12) is distinguished by having vertical and inclined conical water-tubes extending at right angles to the passage of the gases of combustion. It has greater capacity and economy than have the Cornish and Lancashire types, of which it is a development. It is used considerably in England, and is being introduced into the United States. Properly, it should have the internally-fired flue of elliptical cross-section. It has the advantage of not allowing sediment to collect in the tubes. Another development of the plain cylindrical boiler has four or more flues, smaller than those in which internal firing is conducted, and through which the gases of combustion of a fire under the shell pass from back to front after going from front to back underneath. Such a generator is generally termed simply a "four-flue," "six-flue," etc., boiler. Its flues are from 4 to 8 inches across, according to the diameter of the shell.

Multitubular Boilers.—From the above has been evolved the "multitubular" type (*fig.* 10), in which there are from fifty to three hundred tubes of comparatively small diameter, extending from one of the flat heads to the other and serving for the passage of the hot products of combustion. In these the gases may go (without passing underneath) directly from front to back, then into the stack or chimney; but it adds to steam-generating capacity and lessens fuel-consumption per given quantity of steam to cause them first to go under the shell from front to back and then to traverse the flues from back to front, the most usual course then being into the stack. Horizontal multitubular boilers generally have the tubes in rather more than the lower half of their space, and completely covered by water.

Departing considerably from the plain horizontal multitubular boiler is one in some respects like a vertical portable, with separate fire-box, laid on its side, the grate being so placed as to be in the bottom in the new position. Its double fire-box contains water in the "legs" or space between its walls. The tubes running from the tube-sheet in the side are entirely covered with water, as is the crown-sheet or top of the fire-box. As a general thing, however, the extension is of greater diameter than the cylindrical shell, being continued down below the bottom of the latter and generally having straight vertical sides and an externally convex bottom. This boiler has much in common with the locomotive type, which is considered in detail on pages 285 to 287.

Return-tube Boiler.—Figure 3 shows in central lengthwise vertical section a return-tube boiler. The gases, passing over the bridge-wall and the flame-bed, from front to back, return through the flues to the front, where they divide and are sent along the sides to the stack. There is a large central space left between the right- and the left-hand ranks of tubes, to facilitate cleaning and inspection.

Double-deck Boilers have two cylindrical shells, one above the other, connected by two or more vertical "nozzles," which permit the passage of water- and steam-currents. The water is carried high enough to fill

about one-half the upper shell or "drum." Modifications of this type have one lower cylinder or water-drum and two upper cylinders or steam-drums, or two lower and one upper. A common source of danger in such boilers is insufficient size of the connecting-tubes for water-circulation. Figure 5 (*pl.* 73) shows a cylindrical main shell with hemispherical ends and with two cylindrical lower drums, which receive the heat from the hottest gases.

The French or *Elephant Boiler* (*fig.* 1), largely in use in Europe, is not seen in America. It usually has three lower cylindrical drums connected with one drum of much larger diameter. The products of combustion first act upon the lower three cylinders, then return to the front end along one side of the upper drum, then pass to the stack along the other side. The water-level is about two-thirds of the way up in the upper drum.

The Fairbairn Boiler (*figs.* 6, 9) is of the elephant type, and is internally fired. There are three cylindrical shells, two parallel and close together, each traversed concentrically by an internal flue, the third shell being above and between these two, to which it is joined by suitable connecting-tubes. The gases, after leaving the internal flues of the lower shells, return to the front along the sides and bottom of the two lower cylinders, then pass to the chimney between these cylinders and the upper cylinder.

One "compound tubular" type (*fig.* 2) has a large lower shell connected with a smaller upper one, and the lower cylinder has lengthwise tubes throughout its entire volume. The water-level is about half-way up in the upper cylinder.

Locomotive-boilers.—The locomotive-boiler has a horizontal cylindrical shell with a double-walled extension fire-box, sometimes of such diameter as to require a tapering waist-piece to connect it with the main shell. The fire has a direct radiating action upon the sides and the top of the fire-box, from which it passes through hundreds of long tubes of small diameter to the smoke-box, at the farther end, and thence to the stack. (The term "farther end" is used because, as locomotives are ordinarily run, that end of the boiler precedes which would be the back if it were of the stationary type.) The locomotive-boiler has the advantages of being self-contained, of being able to dispense with brick-work, of having an immense heating surface, of having the fire entirely surrounded by water, and of having more space between the crown-sheet and the grate than any other, this latter giving a large combustion-chamber. Figure 5 (*pl.* 74) shows a crude form of locomotive-boiler, the dome having a cast-iron top. The flat heads are held by wrought-iron stay-rods, and the flat crown-sheet above the fire is supported by sling-stays.

Wootten Boiler.—In the Wootten locomotive-boiler there is a comparatively shallow fire-box, extended laterally to any limit desired and usually located somewhat above or only to a slight degree below the lower line of the waist. Interposed between the fire-box and the flue-sheet is a combustion-chamber, and across its fire-box end extends a fire-bridge, so

high as to permit a fire of proper thickness to be carried without allowing fuel to enter the chamber or the tubes. The crown-sheet is stayed directly to the shell by bolts, as are the side-sheets. Figures 8 and 9 (*pl.* 74) give lengthwise and cross-sections of a Wootten boiler, which show more clearly than any description the peculiarities of its construction. It has done remarkably good service upon the Philadelphia & Reading Railroad and on other lines, particularly with the use of low grades of fuel, which could not well be used in any other type of fire-box.

The Marine Boiler has at one end a fire-box that is surrounded by water, and from which flues extend to a combustion-chamber or "back connection," surrounded by water spaces, and running nearly up to the water-line. From the front part of this chamber, above the flues, there extend horizontal return-tubes to the front of the shell. The gases pass through the flues into the chamber at the back, return through the small flues to the front, and enter the up-take. In marine boilers the flame must necessarily be within the shell. In the drop-flue type (generally internally fired) the products of combustion pass up and over a bridge, along tubes to the back, then down through tubes to the front, then again through still lower ranks of tubes to the front, and then to the up-take.

The smaller the bore of the tubes, the stronger they are for a given thickness of metal, or the thinner they may be to afford a given strength; so that the advantage of small tubes is in the lines either of safety, if the thickness is maintained at a standard, or of cheapness and increased steaming capacity, if they are made thinner in proportion to their diameter. Some English locomotives and marine boilers have copper fire-boxes, which, though they have great conductive power, are expensive and lack sufficient strength.

Figures 9 and 10 (*pl.* 75) show a double-ended marine boiler built for the United States cruiser "Baltimore." There are at each end four large internally-fired corrugated flues that discharge into combustion-chambers, from which lead small flues through which the gases travel in the reverse direction to that taken in the large flues. The grates are not illustrated in position, and the up-takes and steam chimneys are not shown. Lengthwise-screwed stays in the steam-room strengthen the shell in a longitudinal direction.

The marine boiler shown in Figures 7 and 8 was constructed for the United States revenue steamer "Lot M. Morrill." There are three corrugated flues which are internally fired. The corrugations strengthen the flues transversely, at the same time enabling them to expand and contract independently of the main shell of the boiler, without causing any injurious strains. The gases of combustion after passing through these tubes pass upward and then reverse their course, going through a number of small tubes that discharge into a common up-take, which is surrounded by steam space. Lengthwise stays of wrought iron supplement the staying action of the tubes in counteracting the tendency of the heads to separate.

Tube-fastenings.—All the above-mentioned boilers are composed of cylinders, either large or small, and those with tubes or flues traversing lengthwise have flat heads, which facilitate fastening the ends of the tubes, so as to give strength and tightness. The larger flues are fastened in the heads by being flanged and riveted; smaller flues have their ends inserted in holes (drilled of the same size as their external diameter), and then so expanded by considerable pressure with a suitable tool that they completely fill the holes. Sometimes, besides being expanded in the holes, the ends of the tubes are slightly extended and are then turned over by a special tool, so as to lie against the flat face of the head. This is termed "beading," and in the opinion of some adds to the efficiency with which the tubes act as lengthwise stays to counteract the tendency of the steam to bulge the heads or to force them apart. Some classes of boilers—notably, those of locomotive-engines—have tubes smaller than the holes in the tube-plates; to fill the holes metal ferrules or rings are placed upon the tube-ends, thus making a more steam-tight joint than could be made by the thin edges of the tube-sheet.

Vertical Boilers.—In the boilers above described the shells are horizontal, but cylindrical boilers are sometimes set vertically, though in such cases the gases of combustion pass vertically only, and generally through a number of small tubes extending from end to end. Such vertical boilers are generally provided with a double-walled extension, styled the "fire-box," having its lower end closed by the grate, the space between the two walls of this fire-box being called the "water-leg" and constituting efficient heating surface. Of this type are a vast number of portable and steam fire-engine boilers.

A vertical boiler in use where there are large quantities of waste gases from iron-furnaces consists essentially of a very long shell inclosed in a mason-work stack (*pl.* 76, *fig.* 12). The intensely hot gases of combustion pass between the stack and the cylinder, to which they impart their heat. To prevent the injurious action of the flames upon the upper portion of the boiler, in which there is no water, that portion is made smaller than the lower and is inclosed with a fire-brick ring.

There are vertical cylindrical boilers in which a number of small water-tubes leave the main shell just above the crown-sheet and enter above the water-level; the entire boiler being set in brick-work or in an iron jacket, the gases of combustion pass among and around these tubes, through which there is a constant upward circulation.

Portable Vertical Boilers.—The simplest form of portable boiler (*fig.* 3) has a single smoke-flue, extending from the crown-sheet or the top of the fire-box through the upper head of the cylindrical shell. The Shapley vertical type (*fig.* 10) has a conical internal fire-box in two sections, the lower containing the greater part of the fire-box, the upper and smaller being principally a steam-reservoir. Short horizontal smoke-flues extend from near the top of the fire-box to an annular space between the two main cylindrical sections, and from this annular space vertical flues

of small diameter lead to an annular smoke-passage around the base. The proper water-level is above the top of the fire-box, about one-quarter of the way in the upper drum.

Figure 4 (*pl.* 76) has a nearly spherical boiler suspended in a cylindrical fire-box with double walls. The gases, which are deflected by the bottom of this suspended water-vessel, pass up from the fire-box through a ring of flues communicating with a smoke-drum, above.

Where vertical portable boilers have several vertical smoke-tubes, they discharge at their upper ends into a common smoke-chamber connected with the stack. In some this smoke-chamber is entirely above the boiler proper; in others it is submerged in the steam, this being the most common type in American steam fire-engines. In the Niles type (*fig.* 11) this submerged smoke-drum is conical.

The Silsby Steam Fire-engine Boiler (*fig.* 2) has an inner and an outer shell with water-leg between; there are vertical smoke-flues from the upper head to the crown-sheet, from which latter there depend concentric circles of drop-tubes, each having a circulation-tube within. In a new form of steam fire-engine boiler (*fig.* 1) the straight drop-tubes of the Silsby are replaced by sectional coil-tubes extending from the water-leg to the crown-sheet.

Coil Boilers (usually vertical) carry most, if not all, their water in long coils of pipe of small diameter. They are characterized by rapid steaming-power and by great safety; but it is necessary to have their feed much more steady and reliable than where there is a considerable mass of water. Their use is principally confined to steam fire-engine and marine service.

Water-tube and Flue Boilers.—Most tubular boilers are distinguished as either "water-tube" or "flue," the tubes of the former serving for the passage of water and the tubes of the latter for the passage of the gases of combustion. In water-tube (sometimes called "tubulous") boilers the pressure upon the tubes is from the inside; in smoke-flue or tubular boilers the pressure is from the outside. In cross-tube boilers there are two parts of the shell, the lower part forming the fire-box and containing water-tubes, and the upper part surrounding the tubes and composing the water-space and the steam-space. The two parts are joined by rings and can be taken apart to clean the boiler or to repair the tubes.

The Circulating Drop-tube, invented by Jacob Perkins, has found its way into many types of boilers. It consists essentially of a vertical tube with closed bottom, which extends into the combustion-chamber or passages for the gases of combustion, and has within it a smaller concentric tube extending nearly all the way down. The course of the water is down the central tube and up through the annular space between the two tubes. The same effect is produced by substituting for the central tube three strips of sheet iron of such width that their cross-section forms a triangle inscribed in the tube-circle. One form of vertical boiler with Field tubes is shown in Figure 6. The arrangement suspended in the centre of the combustion-space is a smoke-deflector, which deflects the gases among the

suspended circulating tubes and keeps them from going straight up the chimney without expending their heat upon the tubes. In the original Field tubes there was a funnel-shaped enlargement of both the inner and the outer tubes, intended to facilitate circulation; but this has been found to be unnecessary. Figure 5 (*pl.* 76) shows a Field tube in detail.

Sectional Generators.—For the double purpose of increasing the heating surface as compared with the amount of water contained, and of diminishing the size of parts so as to lessen both their liability to explode and the damage resulting from their rupture, there have been devised what are called "sectional" generators, having heating surfaces wholly or in great part composed of tubes or spheres containing the water to be heated.

Babcock & Wilcox Boiler.—In the Babcock & Wilcox type, shown in Figure 1 (*pl.* 77), the principal portion is a number of ranks of inclined wrought-iron water-tubes connected at front and back by suitable "headers," which are in connection with a horizontal cylindrical drum, above, in which the water-line is carried about the centre of height. The whole being incased in brick-work, the gases of combustion pass upward from the grate through and among the ranks of water-tubes, their course being held along these tubes by a baffle-plate, so that from the time they leave the combustion-chamber by the grate to their entrance into the smoke-chamber, at the back, they are in contact with the tubes. Nearly the entire front half of the tubes receives heat by direct radiation from the incandescent fuel. There is constant circulation through these tubes, and, as the water at the back and lower portion is more quiet than elsewhere, there is at this part a transverse horizontal mud-drum in which solid impurities may collect. The main cylindrical shell has above it a horizontal crosswise steam-drum. The tubes do not lie above one another in vertical lines, but are "staggered"—that is, one tube lies above the space between two others. They are expanded into the headers, and each has opposite it a hand-hole, to permit perfect cleaning.

The Babcock boiler has as its distinguishing characteristics, among others of the same general class, sinuous headers for each vertical row of tubes; a separate and independent connection with the drum, both front and rear, for each such vertical row of tubes; all joints between the parts of the boiler proper are made without bolts or screw-threads; no surfaces are used which require to be stayed; the boiler supported independent of the brick-work, that it may be free to expand and contract as it is heated and cooled; has large drums; and every part is accessible for cleaning and repair.

The Abendroth & Root Boiler (*fig.* 3) consists of a nest of inclined water-tubes connected at their front and rear ends with a series of horizontal overhead drums, each drum with its underlying row of tubes forming a "section" of the boiler. The Heine boiler is of a somewhat similar type. The Kelly generator has the same inclined tubes, but there is no lengthwise drum; the tubes discharge into a number of vertical chambers connected with a steam-drum set crosswise above them. The

Firmenich boiler has at the bottom two partially cylindrical horizontal wrought-iron shells, one on each side of the grate. Ranks of nearly vertical water-tubes connect these shells with two upper horizontal and nearly cylindrical drums, which have in common a horizontal cylindrical steam-drum.

Figure 5 (*pl.* 77) shows a sectional boiler not known in America. The water is contained principally in a series of rows of conical cast-iron sections connected above and below.

The Harrison Sectional Safety-boiler (*fig.* 2)—a generator characterized by ample combustion-space—is principally composed of cast-iron spheres made in sections of four. These are so connected as to give considerable water-space and are in connection with a suitable steam-drum.

The Sterling Boiler (*fig.* 4) has a horizontal water-drum connected by inclined tubes having bent ends with two upper horizontal water- and steam-drums parallel with the lower drum. The products of combustion pass beneath an arch, striking the tubes connecting the lower with the front upper drum, the tubes being at an angle of 50° with the horizontal. The gases then strike a baffle-plate or partition-wall composed of fire-tiles, and are sent along the front ranks of tubes until they rise above the baffle-plate. They cross to the ranks of tubes connecting the rear upper drum with the lower drum, these tubes being at an angle of 60° with the horizontal and following them downward to the out-take at the rear of the lower drum. The upper drums are connected by two series of pipes arranged above and below the water-line.

Boiler-plate Riveting.—Boiler-plates should have their contacting surfaces planed smooth before riveting. The outer of the two edges of a joint should be bevelled by a planing-machine, and to make the joint steam-tight under great pressure it should be "calked" along this planed edge by repeated blows with a round-nosed tool, to compact the surfaces more perfectly. The strength of riveted joints is only from forty to sixty per cent. of that of the solid plate. Chain-riveting (*pl.* 76, *fig.* 8) is twenty-four per cent. stronger than zigzag riveting (*fig.* 9) and from sixteen to nineteen per cent. stronger than single riveting (*fig.* 7). The tendency of flat boiler surfaces to bulge outward is resisted by stays or tension members, which are either rods, tubes, or plates. If the latter, they are generally called "gussets." At present wrought-iron and steel plates are generally joined by riveting, but hydraulic welding has been attended with some degree of success, and electrical welding has been introduced.

The Horse-power of Boilers is a term frequently misapplied and misunderstood. Strictly speaking, a boiler has no horse-power. The amount of steam that may produce one horse-power in a common non-condensing slide-valve engine might in a compound condensing engine with improved valves develop four horse-power, but if used in heating only, would develop no power. But there is a conventional rating by which one boiler horse-power is assumed to be the evaporation of thirty pounds of water per hour from 70° Fahr. into steam at one hundred pounds gauge-pressure. The

effective heating surface of a horizontal tube is approximately that due to only one-half its circumference. One pound of good coal will evaporate, under favorable conditions, from nine to twelve pounds of water from and at 212° Fahr., the rate of evaporation varying from 1.5 to 1.9 pounds per square foot of heating surface. As vertical surfaces do not absorb heat so well from the gases of combustion as do inclined surfaces, and these not so well as horizontal surfaces, it becomes desirable to give as much inclined and horizontal, and comparatively as little vertical, surface as possible. In horizontal tubular boilers the shell is about ten times more efficient, surface for surface, than are the tubes. One square foot of heating surface at right angles to the current of heating gases, so as to receive them by direct impact, equals four diagonal or eight parallel to their flow.

The interior of every boiler is divided into water-space and steam-room, which terms explain themselves. The portions of the boilers exposed to the hot gases of combustion constitute the heating surface, which is "direct" if it lies directly over the fire-grate or "indirect" if it receives the radiated heat indirectly.

Stack or Chimney.—In the stack or chimney (which has the double purpose of increasing the draught and of carrying the products of combustion to a height at which they will not be offensive) there should be a "damper," generally a flat plate, which is hung by one edge or balanced upon pivots and may be made to close the flue or open it to any degree desired. In some cases there is employed an automatic regulator, in which steam-pressure corresponding to that in the boiler operates a piston or a diaphragm and through suitable mechanism closes the damper in proportion to the rise of the steam-pressure. Where possible, boiler-chimneys should be tall, so as to give them good draught under all circumstances. On damp days or with unfavorable winds many boilers set with insufficient height and cross-area of flue fail to generate steam to full or desired capacity. Rapidity of combustion may be decreased not only by closing the damper in the chimney or in the passage leading thereto, but also by closing the ash-door below the grate or by opening the fire-door above the grate. Considerable increase of combustion may be effected by a blower above or under the grate or by a steam-ejector in the stack.

The Feed is either by pump or by injector (*pl.* 79, *figs.* 1–3). The pump, which may be driven by a special engine or by the main engine, needs no special description. The injector is a device by which the momentum of a jet of steam from a boiler is made to drive a stream of water into the boiler which supplies that steam. That a jet of steam should supply motive force to force into the boiler which supplies it a jet of water that is increased by the condensation of the working-jet itself is apparently a paradox, but these devices are no longer mysteries. The injector has the advantage (shared by an independent feed-pump) of being able to supply the boiler whether or not the main engine is running. Whatever type or types of feeding device are used, there

should be two appliances, each able to supply at least twice as much water as the boiler can evaporate under the most favorable circumstances.

Feed-water Heater.—The feed-water should be heated, where this can be done, by waste steam or by the gases of combustion after they have left the boiler. A good heater raises the temperature of the feed-water to 180° and even to 212° from the normal 62° Fahr. Figure 7 (*pl.* 77) shows an arrangement of feed-heater which generally goes by the name of "economizer." In it the hot gases of combustion, passing from the battery of boilers, go through an arrangement of vertical tubes, through which the feed-water is circulated before going to the boilers. By this means the water is heated nearly to 212° Fahr., thereby greatly assisting the work of evaporation. Such devices are especially good where there is insufficient heating surface in the boiler proper, or where, from the improper position or dirty condition of such surfaces, the water in the generator proper does not sufficiently absorb from the products of combustion the heat which they contain.

Boiler-cleaners.—Boilers are sometimes supplied with horizontal mud-drums, connected with the main shell (or with the lower shell if there are two or more), and placed out of the reach of the hot gases of combustion, so that they will have in them but little circulation and be but little exposed to injury from flame. From these drums the mud, scale, and other impurities which may settle therein can be easily removed. But where the feed-water contains large quantities of mineral substances it is absolutely necessary to have a purifier (generally a vessel containing filtering material such as coke, shavings, etc.), in which exhaust steam from the boiler heats the feed to a high enough temperature to make it drop the lime-salts, the most common mineral substances found in water.

The Mechanical Boiler-cleaner shown in Figure 6 has in the boiler, with its mouth facing front, a funnel, mostly above the water-line, but with its apex below low-water level. From the point there rises and leaves the boiler a tube, which enters at one side of the top of a hollow cast-iron sphere, having a vertical partition extending downward halfway across it. From the other side of this sphere a tube goes through the boiler, entering below the steam-line. The circulation sweeps the mechanically suspended impurities backward and carries them into the sphere, where they are dropped in the settling-chamber, from which they may be blown off, the water returning to the boiler.

Boiler-coverings.—Non-conducting coverings are made of wool-felt, paper-pulp, asbestos, magnesia, plaster of Paris, etc. It may be said of all these that the greater the amount of air inclosed in their pores or left as a jacket between them and the boiler which they encase, the better their heat-insulating properties.

Draught.—Some boilers are given a blast of hot air, others a current of warm air, others, again, a jet of cold air under considerable pressure. In every case the temperature and pressure of the draught may be made to have a considerable effect upon the capacity and economy of the boiler.

Steam-domes.—Additional steam space is often given by vertical cylindrical "domes" at a right angle to horizontal cylindrical shells; and this usage is almost universal on American locomotive-boilers. It has the marked demerit that the dome is expensive and weighty, and, as generally arranged, is a source of weakness to the shell, a large part of which is generally cut away, to permit the boiler to be entered through the hole thus left when the dome is removed. The very small steam capacity which a dome really adds makes its value as a reservoir problematical. Some of the best steaming English locomotives are domeless, and a few American railroads are trying the experiment of leaving off these adjuncts.

The carrying over with the steam of mechanically entangled water may be very largely prevented by compelling the steam to pass through a dry pipe, a long horizontal pipe in the steam-room which has in the centre connection with the steam-pipe and into which the steam can pass only through fine slits or drilled holes, which act as strainers.

Where a boiler generating steam at high pressure is intended to supply the steam to heating-systems, etc., where low pressure is needed, there is interposed a pressure-reducing valve, which prevents the pressure beyond it from exceeding a desired point, no matter what pressure may be behind.

The Fire-grate is usually made of cast-iron sections, called "bars," so constructed that they have a large amount of air-space between them, so that they cannot easily be warped, and that at the same time they can readily be removed. Some of the best are so arranged that they may be given motion between and among one another, to facilitate cleaning the fire. Rocking-grates have sections, called "fingers," which may be worked up into the fire by a shaking-lever. (See p. 286.)

Figure 1 (*pl.* 78) shows a stepped grate, which it is claimed gives more air surface and places the fuel in a better position than does a nearly level grate.

Mechanical Stokers.—Figure 2 shows a continuous mechanical stoker. The grate is in sections, arranged like the apron of a horse tread-mill, and the fuel, being fed in at *B*, is gradually run in under the combustion-chamber, the ashes and the unconsumed fuel dropping off at the back. The entire grate system may be run out upon the tracks *H*. In Figure 3 is shown a mechanical stoker in which the fuel is fed from below by a screw, the intention being to supply it as in the wick of a lamp or candle, so that as it becomes heated the volatile gases will be evolved and ignited. The ashes are run off at the sides of the combustion-pan and fall in an annular passage. In Figure 5 (*pl.* 77) the ash-pan, which is water tight, is filled with water.

In the rather remarkable system shown in Figure 7 (*pl.* 78) the fuel is fired upon an inclined grate and the gases follow the course of the arrows along under the upper shell, between that and the flame-bed or partition; then back under this partition and between it to the middle drum; then back between the middle drum and the lower drum, and then under the lower drum forward to the flue. Thus the coldest gases strike

the bottom shell. The connections between the shells are by only one nozzle, at the end, so that the water and the steam have to follow the same zigzag course as that taken by the gases.

In some cases the bottom of the fire-box is made double and contains water, the grate being at a little distance above it; but, while this may in some measure increase safety from fire, it renders the boiler more unsafe, by reason of the facilities it offers for the deposit of mud and scale upon the lower sheet and the consequent destruction of the plates.

Boiler-setting.—Figure 4 (*pl.* 78) shows an old-fashioned way of boiler-setting. The gases pass from the combustion-chamber, *H*, over the bridge-wall, along the flame-bed, down under and along one side of the lower cylindrical shell, then back again along the other side, under the lower shell, to the flue. The feed is introduced in the lower vessel, where the temperature is lowest. This arrangement makes of the lower drum little more than a feed-heater, with the additional disadvantage that it has to bear the same high pressure as the main shell, above.

Boiler Accessories.—A boiler requires a fire-door to close the fire-box, a grate upon which the fuel is spread, and (if of considerable size) a man-hole by which it may be entered for the purposes of inspection, cleaning, and repair. Small boilers have no man-holes, but are supplied with hand-holes. Man-holes and hand-holes are closed by plates of elliptical form, and of such proportions and dimensions that they can readily be inserted in the holes and turned around, so that the pressure of the steam or of the water inside holds them tightly in place and their blowing out is impossible. The tightness of the steam-joints is further insured by a screw-bolt working through an arched bridge-piece, with ends bearing upon the boiler at the sides of the man-hole or the hand-hole.

The Safety Appliances usually attached to a boiler are the safety-valve, the gauge-cocks or try-cocks, the water-gauge, and the pressure-gauge. There are also, though less generally, recording-gauges having fusible plugs, and low-water alarm- and sounding-gauges.

The Safety-valve is a disc so held down to its seat by weights or springs that it will lift and discharge steam only when the pressure under it reaches a certain predetermined point. It may have either a flat or a conical seat, and the disc may be held to its seat by a plain weight, a spring, or a lever and weight. In any case it is well to have upon each boiler at least one safety-valve, so locked up or otherwise constructed that the pressure at which it will lift cannot be accidentally or intentionally increased. In Figure 8 the safety-valve is shown blowing into the stack —a bad plan, because it increases the draught and urges the fire. Besides this, every one should know when the safety-valve blows. Safety-valves should be lifted twice each day, to be sure that they are not stuck upon their seats; and when they blow off, the pressure at which they do so should be noted by reference to the pressure-gauge, in order to see that they are not blowing at a point above that intended. The pressure at which they quit blowing should also be noted.

The Water-gauge is a vertical glass tube connected at top and bottom with two horizontal fittings, one of which is intended to be in the steam-room and the other in the water-space. The level of the water in the boiler is shown with fair degree of certainty in the tube.

The Try-cock is simply any form of cock that will show by its discharge whether there is water or steam at the level at which it enters the side of the boiler. Try-cocks should be tested two or more times a day, and from time to time should have a steel rod passed through them into the boiler, to free them from incrustation. The same may be said of the connections of the glass water-gauge or column.

The Low-water Device consists of a float which, when the water gets below a certain level, gives an alarm and also causes an increase in the feed and in the water-gauge glass. There are also gauge-cocks or try-cocks, the opening of which will show with reasonable accuracy where the water-line is. In Figure 6 (*pl.* 77) *I* is a float, to which there is attached a rod, passing through a stuffing-box in the shell and intended to show by the position of the weight attached to the chain or cord passing over the wheel (*F*) what is the water-level. A fusible plug is a brass fitting placed in the crown-sheet of a boiler and having drilled through it a hole in which there is a fusible metal rivet, which when the temperature gets above a certain point (determined by the melting-point of the alloy), by the water-level getting below the crown-sheet, will melt and allow steam to escape into the fire-box, putting out the fire and giving an alarm. It must be remembered that the melting-point of fusible plugs rises with use and with time, so that after more than a year or so they are not to be depended upon.

Pressure-gauges.—The dial pressure-gauge (*pl.* 78, *fig.* 6) shows by the distortion of a metal diaphragm or tube the amount of steam pressure put upon it, and this is indicated, through levers and pinions, by an index-hand. By the height of a column of mercury in a tube the mercury pressure-gauge shows the pressure which exists under it. In the differential mercury-gauge (*fig.* 5) there is a piston, having a small head at the lower end to receive heavy pressures, while a larger upper head takes the pressure of mercury in a reservoir communicating with a graduated tube. A very small rise of the piston makes a corresponding great rise of the mercury in the tube. The recording- and alarm-gauge (*figs.* 9, 10) has a diaphragm, which works a crank-shaft and through it an index-hand showing the pressure, and at the same time operating a lever having a pencil-point which records upon a graduated paper ribbon moved by clockwork the pressures shown by the index. The paper strip is marked with transverse lines corresponding to hours, so that the pencil records the pressure for each minute. The whole is enclosed in a glass case, to prevent any one from tampering with it; and when the pressure passes a certain limit, an electrical attachment rings an alarm-bell. It is intended that this appliance shall be kept in the office as a check upon the engineer or the fireman, it being required that it shall be maintained continually in steam communication with the boiler.

The Injector is a device by which the impact of a jet of live steam may be made to force water before it into the boiler from which the steam is taken (which is apparently a paradox), or into another vessel where a pressure exists. The water forced may be lifted by the injector itself or may be supplied thereto under pressure. In either case the range and capacity of its work depend upon the proportion and position of the jets and the excellence of workmanship. Its operation is based upon the fact that a current of any fluid has a tendency to induce movement in its own direction in any body over or through which it passes; and in the injector this movement is intensified by the steam continuously condensing and producing a vacuum, to fill which the water rushes in with a momentum induced by the vacuum alone where the instrument has to lift its water, and increased thereby where the water is fed under pressure. The condensation of the steam heats the water, but some of the heat lost by the steam is converted into the mechanical force necessary to convey the water and to overcome friction, besides that which disappears through leakage, radiation, etc.

Injectors are used not only to feed the boilers which supply them with steam, but also to feed other boilers, fill tanks, put a hydrostatic-pressure test upon boilers, operate hydrostatic presses, etc. They have the advantage over pumps in locomotive-boiler feeding that they will operate when the engine is not running. Considered merely as lifting- and as forcing-pumps, their duty is not satisfactory, but as boiler-feeders there is economy in their use, because they heat the feed-water.

"Little Giant" Injector.—Figure 1 (*pl.* 79) shows, in longitudinal vertical section, the "Little Giant" injector, a simple type of feeding injector for stationary boilers which are used where the water need not be raised or "lifted," but may be fed from a tank or street-main. *A* is the regulating handle, *B* the steam inlet, *C* the water inlet, *D* the overflow, and *E* the discharge to the boiler. This injector is started by opening the water-valve (an ordinary stop-valve, not shown in the Figure). When the water shows at the overflow *D*, the steam-valve (not shown in the cut) is opened full. The quantity of water fed in is regulated by moving the handle *A* to the left or to the right. This handle, in starting, must be in a vertical or nearly vertical position, so that the "combining" tube shall not touch either the steam-nozzle or the discharge-jet.

Giffard's Injector.—In Giffard's injector (*fig.* 2) the injection of the supply of feed-water is effected by the pressure and condensation of steam from the boiler. The operation of the apparatus is as follows: steam escaping from the boiler through the pipe *a* is compelled to pass through the contracted nozzle seen below in inlet-pipe *b*, by which its velocity is greatly increased. The feed-water from the pipe *b* is drawn into the annular space surrounding the nozzle, and, mingling with the condensed steam, is driven through the pipe and valve *c* into the boiler.

The Fixed-nozzle Automatic Injector shown in section in Figure 3 (*pl.* 79) can, without the aid of any special valves or fittings, be used either to

receive the water-supply under a head or to raise it a considerable height before delivering it into the boiler; besides, it does not require the adjustment of both the water- and the steam-supply to start it either originally or after the jet breaks. The amount of water delivered is regulated (whether the instrument lifts its water or is supplied under pressure) by the water-valve operated by a screw and a hand-wheel, or by both these and the steam-plug. In the illustration *A* is the body or case, *B* the steam-connection, *C* the water-supply connection (in which the water-regulating valve *R* is placed), *D* the water-delivery, containing a check-valve, and *N* the overflow-valve. To work the apparatus when the water is lifted, the steam-spindle *S* is opened half a turn, and when the water shows at the overflow the steam-spindle is turned further until the overflow ceases. When the feed-water is under pressure, the water-regulating valve *R* is opened, and then the steam-spindle is opened all the way.

The Hancock Inspirator (*pl.* 79, *fig.* 5) is a double apparatus practically composed of two injectors, one of which is constructed especially for lifting and the other for forcing when fed under pressure. The first draughts the water and delivers it to the second, which forces the feed-water to the boiler. The two are combined as one instrument.

The Separator is an important addition to the ordinary boiler, as it tends to eliminate from the steam the unevaporated globules of water which are mechanically entrained by the current of outgoing steam, and the condensed steam which is the result of loss of pressure through friction and radiation. It works by reason of the fact that the entrained water has a slightly greater specific gravity than the steam which carries it along. It exists in many forms, the simplest being known as a "dry-pipe" separator, consisting of a horizontal pipe closed at both ends and extending into the steam-space. It connects with the steam supply-pipe by a T in its middle, and has cut or bored throughout its periphery narrow slits or small holes which strain out the water. The separator proper is applied outside the boiler. One form (*pl.* 79, *fig.* 6) consists of a vertical cylinder having an internal central pipe which forms the outlet pipe, and which extends from the top downward about half its height. The steam enters tangentially to the annular space between the inner and outer pipe at the side near the top of the apparatus. The speed of the incoming current produces centrifugal action, which causes the steam to pass in a spiral line around the internal pipe down to its lower end, where it abruptly changes its direction, passing upward through it, and out at the top to the point where the steam is to be used. The entrained water thus separated is thrown to the outside of the downward current and falls into a collecting-chamber below, whence it can be blown off by hand or can be automatically drawn off by a pump or trap, and returned to the boiler with little loss of temperature. A glass gauge is attached to guard against an over-accumulation of water.

2. THE STEAM-ENGINE.

Historical.—The use of fire for forging metals, heating water, making bread and the like was known at a very early day in history (Gen. iv. 22; xviii. 6), but we have no knowledge as to the time when this serviceable element was discovered. "Probably it was one of man's very earliest acquisitions, being the agent he has most constantly employed in the preparation of his food. Flints have been found that have been subjected to the fire for the purpose of breaking them into small and angular pieces, and the charcoal and ashes of ancient hearths have been exhumed in deposits which competent geologists place as remote in time as the Interglacial period." Implements of bronze have come down to us from prehistoric times, and these also give evidence of the very early use of fire. But its employment for converting water into steam for practical purposes is of comparatively recent date.

Hero's Æolipile.—The first recorded instrument for illustrating the power of steam was that described by Hero of Alexandria in his *Pneumatica* about 120 B. C., though there is nothing in the text to indicate that it was his invention. It was named the "æolipile" (*pl.* 80, *fig.* 1), and consisted of a boiler partly filled with water and placed over a fire. Over the boiler there was pivoted on two bent tubes a spherical vessel ("steam-turbine") which was supplied with steam through one of the pivots from the boiler below. Projecting from the sphere in a direction perpendicular to the axis of rotation were two bent pipes, through which the steam escaping into the air exerted a force in a contrary direction, after the manner of Barker's mill (p. 37), thus causing the sphere to revolve. It is not known that the æolipile was ever more than an amusing toy, though some have supposed that it was applied by the Greek priests for producing motion of apparatus in their temples.

Further trace of the force of steam is lost in history until the time of Justinian (A. D. 554), when it was employed by Anthemius, architect to the emperor, to frighten his neighbor Zeno, by connecting tubes to the cauldrons of water and extending them up into the building, so that when the steam ascended the house was shaken by the escape of the imprisoned air. Alberti, the Florentine architect, notices (A. D. 1412) the prodigious expansion by heat of water shut up in the cavities of some stones, "which blows up the whole kiln with a force altogether irresistible."

If the statement of Spanish writers that Blanco de Garay, A. D. 1543, applied steam to the propulsion of a ship at Barcelona, is apocryphal, as the majority of writers on the subject believe it to be, there was made from the time of Hero to the seventeenth century no practical application of the power of steam worthy of special illustration. Here and there are found evidences of a knowledge of its force in its employment for trivial purposes, such as blowing organs and turning spits, but it devolved on a later period to demonstrate its power in its application to the performance of important and useful work.

John Mathesius (1567) hinted the construction of a machine in which "the volcanic force of a little confined vapor might be made to perform the work of horses or water." The "Pneumatics of Hero" were in 1587 translated into the Italian, which drew attention to the "ingenious toys," as they have been called, in which "air" was applied with great skill to produce motion. Sir Hugh Plat describes (1594) the construction of "a rounde ball of copper or latten that will blowe the fire very stronglie by the attenuation of water into aire."

Porta's Steam-engine.—In 1601, Giovanni Battista della Porta, in a treatise on pneumatics, described an apparatus for raising a column of water by the pressure of steam. Figure 2 (*pl.* 80), from Porta's book, shows the furnace surmounted by a boiler, above which is a tank nearly filled with water. As the steam from the boiler enters the tank near the top, the water is driven out through the curved pipe.

Previous to 1605 steam was employed in artillery instead of gunpowder. Rivaul in 1608 announced the invention in the form of a problem, "How a cannon might be fired with pure water."

De Caus's Steam-fountain.—Salomon de Caus (1611) was employed by the prince of Wales to decorate his gardens at Richmond in Surrey. He clearly understood the action of the "air" in "Hero's fountain," and improved the machine by the insertion of valves to prevent the return of the water which had been elevated, though he did not observe that it was the expansion and condensation of the vapor in the air that mainly produced the effects in the Egyptian machine and in his own. Had De Caus made a coal fire under his improved fountain, he would have had a good steam-engine. In 1615 he suggested forcing water by a steam-fountain from a vessel by the expansion of steam within the same. In Figure 3, taken from a drawing probably made by De Caus's own hand, *A* is a spherical boiler containing water, *B* is the cock at the extremity of the pipe which takes water from the bottom of the vessel boiler at *C*, and *D* is the cock through which the boiler is filled. The elastic force of the steam formed in the boiler by the application of fire drives the water out through the vertical pipe.

David Ramsey and Thomas Wildgosse patented in 1618 a compendious form of engine to plough ground without horses or oxen, to raise water from any low place to high places for well-watering cities, towns, and gentlemen's houses, and to make boats run upon the water as swift in calms and more safe in storms than boats full-sailed in great winds. In 1630, Ramsey took out another patent of nine claims, the second of which reads, "To raise water from lowe pittes by fire;" and this is considered the earliest notice of an engine for raising water by fire in England.

In 1629, Giovanni Branca published at Rome an account of an engine, shaped like a water-wheel, which was driven by steam issuing in a jet from a boiler and impinging on the vanes of the wheel (*fig.* 4).

Worcester's Steam-engine.—Tradition relates that the marquis of Worcester had the first glimpse of his steam-engine when he was a

prisoner in the Tower of London in 1655. The marquis wrote (about 1659) his celebrated manuscript entitled "A centurie of the names and scantlings of such inventions as att present I can call to mynde to have tryed and perfected." The sixty-eighth scantling of this manuscript announces the great invention which has popularized and preserved the fame of this wonderful inventor in the public mind. He calls it "An admirable and most forcible way to drive up water by fire," etc. Worcester's ninety-ninth scantling can be explained only by the use of a piston in a cylinder with water under it. In 1663, Worcester, in his *Century of Inventions*, describes an engine no drawings of which are extant, but which his biographer, Dircks, has suggested was like the sketch shown in Figure 5 (*pl.* 80). Two vessels (*A*, *A*) are connected by a steam-pipe (*B*, *B*) with the boiler *C*, which is placed behind them. *D* is the furnace. A vertical water-pipe (*E*) is connected with the cold-water vessels *A*, *A*, by the pipes *F*, *F*, which reach nearly to the bottom. Water is supplied by the pipes *G*, *G*, containing valves (*a*, *a*), and dipping into the well *H*. Steam being admitted from the boiler to each vessel *A*, *A* alternately, is there condensed, and the vacuum formed permits the pressure of the atmosphere to force the water from the well through the pipes *G*, *G*. While one is being filled, the steam is forcing the water from the other up the discharge-pipe *E*. As soon as one is emptied the steam is shut off and turned into the other, and the condensed steam remaining in the vessel permits it to fill again. Worcester's apparatus was not an engine in the proper sense, but a water-raising machine. One of Worcester's engines of about two horse-power was in use at Vauxhall in 1656, but the hopes of its inventor were not realized, as it never became a commercial success.

Mr. Boyle, while experimenting with æolipiles in 1678, observes, "The elastical power of the steam seems manifestly due to the heat that expands and agitates the aqueous particles whereof the steam consists;" and he considered that these were alone condensible, while air was not—the explanation of a fact which may be said to have laid the foundation of the condensing steam-engine. Hautefeuille in 1682 introduced alcohol into a cylinder and evaporated and condensed it *tour-à-tour*, without allowing it to escape or be lost in the processes. In 1682, "Sir Samuel Moreland announces his principles of the new force of fire. Water being evaporated, these vapors immediately acquire a greater space, and, too forcible to be always imprisoned, will burst a piece of cannon. But, being governed according to the rules of statics and reduced to science, weight, and measure, they will then peaceably carry their burden, and thus become of great service to mankind."

Papin found, in 1690, that "a small quantity of water converted into steam by heat had an elastic force like that of air, but when exposed to cold was again resolved into water, so that no trace of its elastic force remained." He constructed a machine wherein water, by means of no very intense heat, produced that perfect vacuum which he could not obtain by firing off gunpowder. Papin further says, "Immense power may be

accumulated by the enlargement of the piston that can be employed to draw water or ore from mines or propel ships against the wind."

In 1695, Papin still further developed the power of steam by improvements in the method of making it. The flame and air were made to descend through the fuel, completing the combustion. The smoke was conducted through the boiler in a zigzag immersed flue, and, still further to hasten the evaporation, he used his rotary fan to blow the fire.

Chinese Æolipiles.—The æolipile was applied to new uses at Pekin in 1694. Two experiments were made with it before the emperor Caus Hi. In the middle of a wagon about two feet long was placed a brazen vessel full of live coals, and upon them an æolipile, the wind of which came through a little pipe upon a sort of wheel made like the sails of a windmill; this wheel turned another, and by that means set the wagon in motion for hours together. This wagon was furnished with mechanical devices by which it could be turned around in any given circle. The same contrivance was likewise fixed to a little ship with four wheels. The æolipile was hidden in the middle of the ship, and the wind from two small pipes filled the sails and made it wheel about a long while.

Savery's Steam-engine.—The first successful experiment with the steam-engine, or "fire-engine," as it was then called, was by Thomas Savery, who in 1698 obtained a patent the title of which reads, "A grant to Thomas Savery, Gentl., of the sole exercise of a new invention by him invented, for raising of water, and occasioning motion to all sorts of mill-works, by the impellant force of fire, which will be of great use for draining mines, serving towns with water, and for working of all sorts of mills when they have not the benefit of water nor constant winds." This machine, which was applied to raising water from the deep mines of Great Britain, was an adaptation of Worcester's "fire-engine." It required for what we know as a "horse-power" (that is, the equivalent of 33,000 pounds lifted one foot high in a minute, or 550 pounds lifted one foot high in a second) the combustion of thirty pounds of coal. Savery's device possessed neither cylinder, piston, crank, nor fly-wheel—in fact, no moving parts. The model of his machine (*pl.* 80, *fig.* 6), a description of which he presented to the Royal Society, consisted of a furnace (*A*) heating a boiler (*B*), which was connected by pipes (*C*, *C*) with two copper receivers (*D*, *D*). From the bottoms of these receivers were led branch-pipes (*F*, *F*) turned upward, which were united to form a "forcing-pipe" (*G*); from the top of each receiver was led a pipe turned downward, and these two pipes united formed a supply-pipe which extended to the bottom of the well from which the water was to be drawn. Steam being generated in the boiler *B*, and the cock *C* being opened, the receiver *D* is filled with steam. Closing the cock condenses the steam in the receiver, in which a vacuum is created, and the pressure of the atmosphere forces the water up through the supply-pipe from the well into the receiver. Opening again the cock *C*, the check-valve in the suction-pipe at *E* closes; the steam drives the water out through the forcing-pipe *G*, the clack-valve *E* on that pipe

opening before it. The valve C is again closed, the steam again condenses, and the operation is repeated. While one of the two receivers is discharging the other is filling, and thus the steam is drawn from the boiler with tolerable regularity, and the expulsion of water takes place with similar uniformity, the two systems of receivers and pipes being worked alternately by the single boiler. A modification of this employed surface-condensation to hasten the work. Désaguliers, in 1718, substituted jet- for surface-condensation. Blakely, in 1766, interposed a cushion of oil between the water in the reservoirs and the steam which drove it out.

Savery's engine, which was subsequently much improved, was extensively employed in pumping out mines, and was occasionally used in raising water to supply houses in towns and for driving mill-wheels. Though it was entirely displaced by Newcomen's engine, its inventor must be awarded the credit of having first practically employed the steam-boiler, without which Newcomen and Cawley could not have set their more advantageously acting machine in motion. The piston moving in a cylinder was proposed by Huygens in 1680.

Papin's Steam-engine.—Denis Papin, a humble French physicist, endeavored in 1688 to improve Huygens' apparatus, but having unsuccessfully tried gunpowder, he proposed in 1690, while professor at Marburg, the substitution of steam for producing a vacuum under the piston. Papin's engine (*pl.* 80, *fig.* 7) was constructed practically on the same principle as Huygens'. Instead of gunpowder a small quantity of water was introduced into the cylinder through an opening in the piston, and the opening was then closed by means of the rod M. A fire being started beneath the cylinder, whose bottom was of very thin metal, steam was rapidly generated, and by its elastic force overcame the weight of the piston B and the pressure of the atmosphere, and drove the piston to the top of the cylinder, where a latch E, engaging a notch in the piston-rod, and kept in contact with the latter by a spring, held it up. On removing the fire, there followed a condensation of the steam, by which a vacuum was produced below the piston, and, upon disengaging the latch, the piston, being forced down by atmospheric pressure, raised the weight attached to the rope L passing over the pulleys T, T. The cylinder had a diameter of two and a half inches. Papin's was the earliest cylinder-and-piston steam-engine, but he was not successful in perfecting his apparatus, though he devised various transmitting mechanisms for the motion of the piston, especially for propelling a vessel.

Newcomen's Steam-engine.—It was reserved for the Englishmen Newcomen and his assistant Cawley to make a practical application of Papin's plan of using steam, which was effected in 1705 by connecting with a steam-boiler a cylinder containing a piston. It was a steam-engine, but employed the pressure of the atmosphere to move the piston and to do the work, and hence was called an "atmospheric steam-engine," which proved to be well adapted for working the main rods of pumps in mines, and, later on, for driving revolving shafts. Figure 8 represents a Newcomen

machine in its higher form of development. Immediately upon the dome-shaped boiler, half sunk in a brick furnace, is seen the cylinder with its movable piston. A chain fastened to the piston is placed over a segment attached to a wooden double-armed lever or "beam." This beam at its centre swung upon a pivot, and was united with a connecting-rod, a crank, and a revolving shaft provided with a fly-wheel; and suspended to it were two rods properly secured by chains to two segments. The cylinder, being entirely open on top, allowed the atmospheric pressure to act upon the piston and to set it in motion, together with the described mechanism, when a vacuum was formed in the lower space by the condensation of the steam admitted into it. It is, therefore, worthy of notice that the actual motive-power was not steam, but atmospheric pressure left free to act by the condensation of steam. The use of the chain referred to did not even allow of the direct action of the steam. This machine took twenty pounds of coal per horse-power per hour.

In the first machines the condensation of the steam was effected by simply throwing cold water in a shower over the outside of the cylinder. In an improved form of construction it was effected by injecting into the cylinder a jet of water taken from a reservoir, shown on top of the Figure, and kept constantly filled by the machine itself. This improvement was suggested by an accident: "As they were at first working, they were surprised to see the engine go several strokes, and very quick together, when, after a search, they found a hole in the piston, which let the cold water in, condensing the steam in the inside of the cylinder." The alternate admission and exclusion of steam, originally effected by a workman opening and closing a cock with his hand, were here effected by a mechanism connected with a vertical rod, seen in the illustration in front. The valve-gear was first made to work thus automatically in 1713 by a boy, Humphrey Potter, who caused the beam itself to open and close the valves by means of suitable catches and strings; but in 1718, Henry Beighton substituted for the latter a plug-rod, which worked the valves by means of tappets. Smeaton improved this type, in 1774, by oakum cylinder-packing, and by raising the water used for condensation by a pump worked from the main beam; he also covered the lower side of the piston with wooden plank, to reduce unnecessary and untimely cylinder-condensation.

Watt's Steam-engines.—After Newcomen's engine had been in use more than fifty years, and had been much improved in its mechanical details, it was entirely superseded by the condensing steam-engine invented by James Watt, a mathematical-instrument maker at the University of Glasgow, who in 1763, having put a model Newcomen engine in order, and having been struck with its enormous consumption of steam, began a series of improvements which finally rendered the steam-engine universally applicable. Watt's improvements consisted in lagging the boiler, pipes, and cylinder with non-conductors, in condensing in a separate vessel, and in making the engine double-acting by closing the cylinder at the top and passing the piston-rod through a steam-tight stuffing-box. In

1774 he produced a beam-engine in which the steam passed above the piston and depressed it, raising the weight of the pump-rods, the lower end of the cylinder being in communication with a separate condenser; then a valve was opened, allowing the steam which was above the piston to flow beneath the piston, which was raised by the weight of the pump-rod. He introduced the "air-pump" to relieve the condenser of air and of an excess of water, and used oil and tallow for lubricating the piston instead of water, which caused excessive cylinder-condensation. In 1781 (in order to avoid the payment of royalty upon the crank, which was patented) he employed the "sun-and-planet" movement, to produce a rotary from a reciprocating motion, and added a fly-wheel and a shaft, so that it could drive machinery. In 1782 he patented the use of the expansion of steam—the application of steam on each side of the piston alternately, the opposite side being in communication with the condenser—the double or coupled engine, and the use of a rack upon the piston-rod, working upon a sector on the beam, to give perfect straight-line motion to the rod. For guiding the piston-rod in a straight line Watt also provided the so-called "parallel motion." In 1784 he added the poppet-valve, the centrifugal ball-governor acting on a throttle-valve (*pl.* 82, *fig.* 5), and the steam-jacket. He also invented the indicator by which the occurrences in the cylinder might be made known and regulated; and patented a locomotive steam-engine.

Watt's Condenser.—Watt's most important improvement on Newcomen's machine was the addition of the condenser in 1765. Figure 9 (*pl.* 80) illustrates such an apparatus. Instead of effecting the condensation in the cylinder itself, there was placed under it an hermetically-closed iron box into which the steam from the cylinder was introduced and condensed by an injected spray of cold water. But as the injected water as well as the condensed steam would in a short time entirely fill the box, a pump (seen on the right in the cut) was connected with it, by means of which the water and also the air contained in it could be constantly sucked up and removed. This pump is therefore called the "air-pump."

Three-port Slide-valve.—By adding the three-port slide-valve, invented in 1799 by Murray, and intended to replace the distributing-cock originally used and the valves later on substituted for it, we have the modernized form of the principal part of the machine—namely, the cylinder with its immediate mechanisms—shown in Figures 11 and 12 (*pl.* 80), in which the fresh inflowing steam is indicated by the whitish color in the engraving. It will be seen that the steam is conducted from the boiler, by means of the steam-pipe D, first into the steam-chest C, E, and passes thence in Figure 12 above, and in Figure 11 below, the piston K by means of the steam-passages d, e and f, g in the direction of the arrows. Hence in Figure 12 the piston is forced down, in Figure 11 upward, being, however, operative only if the steam already used and standing above or below the piston can pass into the condenser. For the latter purpose again serve the passages g, f and e, d, further the exhaust-pipe O, and finally, as also

for the alternate admission of the steam, the three-port valve *A*, *B*. This valve is given the positions required for the distribution of the steam, which are indicated in Figures 11 and 12 (*pl.* 80), by the machine itself, by means of a mechanism connected with the valve-rod *F*. The other parts are the piston-rod *G* and the stuffing-box *S*, while the aperture seen in the centre of the bottom is closed by a cock through which the water collected in the cylinder is from time to time discharged.

Figure 4 (*pl.* 82), which represents a modern Watt's engine of the most perfected type, exhibits only a portion of the parallelogram connecting the piston-rod with the oscillating beam. This Figure also shows the solid frame consisting of six columns, an iron foundation, and an architrave-like upper support, in which Watt enclosed his perfected machine, thereby considerably increasing its solidity.

The jacket in which Watt enclosed the cylinder to prevent the cooling off of the steam therein is more plainly recognized in Figure 6, which represents in section the steam-cylinder with jacket (*K*) and the air-pump with the condenser *J* concentrically arranged around it. *A*, *B* is the frame carrying the engine, and *C*, *D*, *E*, *F*, *G* a mechanism replacing Watt's parallelogram. Beighton used for feeding the boiler the heated water of condensation, when it was soft; but when it was hard, he heated the feed-water by a coil passing through the condensing-water. The first inventions by Watt were based less upon the properties of steam than upon the phenomena of heat, because by the peculiar construction of the condenser and of the steam-jacket, as well as by the closure of the upper portion of the cylinder against the entrance of cold air, he prevented the losses which, in an economical respect, made Newcomen's machine practically useless for many purposes. He also later on planted the germ of an improvement which occupies the foremost rank as regards the advantageous application of the steam-power, by the utilization of the expansive action of steam. This action commences when the supply of steam is shut off and the steam in the cylinder is left to itself before the piston has arrived at the end of its stroke. Though the steam from the boiler is shut off, the piston continues to be pushed forward by the steam through the expansive force which constantly becomes weaker. Thus, for instance, a given quantity of mechanical effect is produced by the gradual expansion of the steam to double its normal volume, and consequently to half the normal tension that would otherwise be produced by double the quantity of steam. For the purpose of ascertaining the exact amount of this gain of effect it is necessary to determine the specific relation existing between the tension and the volume of this shut-off expanding steam, a problem of physical science on which much ingenuity has been expended since Watt's time.

Watt's Indicator.—To ascertain empirically the complex result of all these and other component activities on a machine, Watt devised and used an instrument called an "indicator," which, as improved by Richard, is shown in its modernized form in Figure 10 (*pl.* 80). This instrument when

connected with the inner space of the steam-cylinder indicates graphically, by a closed curve upon a strip of paper, the varying steam-pressures succeeding one another during the duration of a stroke. This is effected by means of a piston which on the one hand is connected by a spring with the indicating mechanism, and on the other hand is subjected to and actuated by the same varying steam-pressure in the cylinder as is the large piston. From the diagram traced by this instrument the effect of the steam during a stroke can be calculated, a counter (*pl.* 82, *fig.* 1) connected with a rotating portion of the machine indicating the number of strokes made in a given time, and a water-meter (*fig.* 2) measuring the quantity of steam conducted into the cylinder during the time. These observations form the elements for the calculation of the degree of effect or utility of the steam-engine, and from them also the capacity in horse-power and the consumption of steam per indicated horse-power are calculated.

Dynamometer.—Another apparatus, the dynamometer (see p. 385), is used to indicate the effective or actual amount of power given out by the engine. The dynamometer is fastened upon the shaft of the fly-wheel, and its indication of the effective result in horse-powers, when subtracted from the indicated horse-power calculated from the indicator curves, shows the amount of mechanical force consumed in moving the mechanism of the engine by friction and inertia. In this manner it has been determined that modern machines carefully constructed according to Watt's system produce six times as much effect with a given quantity of coal as Newcomen's.

The development of the steam-engine to its completed form, as shown in Figure 4 (*pl.* 82), was not, however, Watt's work alone. As already mentioned, the three-port slide-valve, described in Figures 11 and 12 (*pl.* 80), was invented by Murray, while the crank mechanism and the fly-wheel originated with other English inventors and mechanics. It was but natural that Watt and his co-workers should only gradually and cautiously, step by step, have developed the actual steam-engine from the atmospheric motor of Newcomen. The pressure they employed was never much above that of the atmosphere, and they even attempted to have passed an act of Parliament forbidding the use of high pressure for the reason that it endangered the lives of the public.

High Pressure.—The idea that steam of high pressure possessed more advantageous properties than steam of low pressure gradually gained ground, and led to experiments with a pressure of from 150 to 300 pounds to the square inch. But the increased danger, the more rapid wear of the machines, and especially the considerable loss of steam by leakage, rendered these experiments so unsuccessful that in practice there was only a gradual progress up to 45, 60, and 90 pounds, and it is only in later practice that we find pressures of 100 pounds and upward in ordinary use. Though with these higher tensions the condenser can be dispensed with, it nevertheless considerably increases the efficiency in cases where the

expansive effect is to be turned to the best account, and as these cases occur more frequently the gain is considerable. Hence the endeavors to use a higher degree of expansion go hand in hand with the efforts to use higher tensions, so that at the present time the utmost is accomplished in this respect.

Hornblower's Compound Steam-engine.—In 1781, Jonathan Hornblower, a contemporary of Watt, patented a "compound" or double-cylinder engine (*pl.* 81, *fig.* 3) whose cylinders (*A*, *B*), which were of unequal sizes, were placed side by side, while the piston-rods *C*, *D* of both were attached to the end of a beam overhead. Steam is led to the cylinder *B* through the pipe *G*, *Y*. The cocks *a*, *b*, *c*, and *d*, which are adjustable so as to let the steam into and from the cylinders, are moved by the plug-rod *W*, which actuates handles not shown in the illustration. *K* is the exhaust-pipe leading to the condenser. The cocks *c*, *a* being opened and *b*, *d* being closed, the steam passes from the boiler into the upper part of the cylinder *B*, communication at the same time being opened between the lower part of *B* and the upper part of *A*. Before starting the engine the steam is shut off from the cylinder, which, by reason of the great weight of the pump-rod *N*, causes the pistons to rise to the tops of their respective cylinders. The engine being freed of air by opening all the valves and permitting the steam to drive through the cylinders and out of the condenser through the "snifting-valve" *O*, the valves *b*, *d* are closed and the cock in the exhaust-pipe is opened. The steam beneath the piston of the cylinder *A* is immediately condensed, and the pressure on the upper side of the piston causes it to descend, carrying the end of the beam with it, and thus raising the opposite end of the beam and its attachments. At the same time the steam from the lower end of the high-pressure cylinder *B* is let into the upper end of the large cylinder *A* by the pipe *Y*, and the completion of the downward stroke finds a cylinder-ful of steam transferred from one to the other, with a corresponding increase of volume and decrease of pressure. When the pistons have reached the bottoms of their respective cylinders, the valves at the top of the small cylinder *B* and at the bottom of the large cylinder *A* are closed and the valves *c*, *d* are opened. Steam from the boiler now enters beneath the piston of the small cylinder, the steam in the larger cylinder is exhausted into the condenser, and the steam already in the small cylinder passes over into the large cylinder as the piston rises. Thus at each stroke a small cylinder-ful of steam is taken from the boiler, and the same weight occupying the volume of the larger cylinder is exhausted into the condenser.

Leupold's Steam-engine.—The high-pressure steam-engine—that is, an engine which is rendered effective without the assistance of atmospheric pressure—was first proposed by the prolific German technical writer Leupold in 1724, in his *Theatrum Machinarum*, from which our illustration (*fig.* 1) is reproduced. It consists of two single-acting cylinders (*r*, *s*) which receive steam alternately from the same steam-pipe through a "four-way" cock (*x*), and exhaust into the atmosphere. The pistons *c*, *d* are

thus alternately raised and depressed, which action raises and lowers the pump-rods *k*, *l* by means of the levers *i*, *i* to which they are attached. The alternate action of the steam-pistons is secured by turning the cock *x* first into the position shown in the Figure, and then, at the completion of the stroke, into a reverse position, by which change the steam from the boiler *a* is led into the cylinder *s*, and the steam in *r* is discharged into the air. Leupold acknowledges his indebtedness to Papin for the suggestion of the peculiar valve employed.

Bull, in 1798, produced the Cornish single-acting pumping-engine without working-beam, the weight of the engine piston and pump plunger being carried by a weighted balance-beam. Oliver Evans introduced the non-condensing high-pressure stationary engine which was the forerunner of most of our modern engines. Cugnot, Stephenson, and others applied the steam-engine to railroads; Stephens, Fitch, Evans, and Fulton, to steamboats.

Evans's Steam-engine.—In 1779, Oliver Evans, an ingenious American mechanic, devised the first permanently successful non-condensing engine in which the power was derived exclusively from the tension of high-pressure steam. In 1772, when but seventeen years of age, he turned his attention to the discovery of "some means of propelling land-carriages without animal power." Observing the power of steam exerted on a wad rammed down over a small quantity of water in a gun-barrel, from which, through the heating of the barrel in a blacksmith's forge, the wad was expelled accompanied with a loud report, he fancied he had discovered a new source of power. Meeting about this time with a description of a Newcomen engine, he was surprised to find that the elastic force of confined steam was not there utilized, while the piston was moved by atmospheric pressure. This he believed to be an erroneous application of the force of steam, and he conceived the idea of a high-pressure engine using steam at a pressure of about 120 pounds per square inch, which he proposed to apply to the propulsion of carriages.

Evans's "Columbian" Engine.—In 1800 or 1801, Evans began the construction of a steam-carriage to be driven by a non-condensing steam-engine, but, changing his plans, he built a beam-engine having a cylinder 6 inches in diameter and 18 inches stroke, with which he successfully drove a plaster-mill. This "Columbian" engine (*pl.* 81, *fig.* 2), as it was called, had a beam supported at one end by a rocking column. The connecting-rod was attached to the other end and drove a crank below; the piston-rod was connected directly to the beam at a point nearer the connecting-rod, and the feed-pump piston-rod was also directly connected at a point nearer the beam-fulcrum. The beam and piston-rod constituted a sort of parallel motion. In 1804, Evans produced the steam-dredge "Oruktor Amphibolis," which had a five-horse-power engine similar to the "Columbian." (See Vol. V. p. 172.) About the same time one of his engines, which was built for a steamboat on the Lower Mississippi, was put to work in driving a saw-mill.

Cartwright's engine of 1798 took steam above the piston, the rod of which extended upward to a cross-head driving cranks above, and downward to an air-pump piston which had the same stroke as that of the steam-cylinder. The bottom of the steam-cylinder was in communication with the condenser, the steam-piston having in it a valve which was opened automatically when the full stroke had been made. The air-pump removed the excess of air from the condenser, which was composed of two concentric cylinders within and around which the water of condensation flowed, while the exhaust steam passed into the annular space.

In 1802, Richard Trevithick of England patented a model steam-engine carriage in which high-pressure steam was employed and the condenser was dispensed with.

During the first half of the nineteenth century progress in steam-engineering was very largely in the direction of the application of the steam-engine to the propulsion of road-carriages, locomotives, and vessels; there were but few striking innovations, each inventor and builder striving to perfect construction rather than to start out in a new field of original design. Those desirous of tracing in somewhat greater detail than is here given the growth of the steam-engine during the period mentioned, will find it in the sections devoted more particularly to the locomobile, the locomotive, and the marine steam-engine. The "Oruktor Amphibolis" of Evans (1804), Trevithick's steam-carriage (1802), the steam-carriages of Griffiths, of Gurney (1827), and of Hancock (1831) show a development as interesting as it was important. The locomotives of Trevithick (1804), Hedley (1812), the Stephensons, Horatio Allen, Peter Cooper (1829), Baldwin (1831), and Jervis (1832) marked a gradual growth rather than startling flights of invention.

Corliss introduced the straight girder frame for stationary engines; he also introduced the plug-valve, and made the detent cut-off, as applied thereto and operated by the centrifugal governor, a mechanical and commercial success. Hartnell brought out the shaft governor controlling the eccentric throw, and J. W. Thompson made it practicable and successful in connection with a balanced valve. John E. Sweet has carried the "straight-line" system of construction to a satisfactory conclusion; and to Charles T. Porter more than to any other man do we owe the success of the modern high-speed automatic cut-off stationary engine. Ball has made a good start in the line of governing by load rather than by speed, and Westinghouse has made high-speed single-acting engines, both throttling and automatic cut-off, compound and non-compound, practicable in a high degree; while, among others, Wootten, Stevens, and Strong in the United States, Mallet in France, and Worsdell and Webb in England, have done much to lift the locomotive out of ruts of design.

Having considered the steam-engine from an historical standpoint, with reference both to its design and construction, we shall now consider it from a more strictly technical standpoint. We shall minutely define and scientifically describe it, and shall then give those details which

would be out of place in a chronological narrative of its development and growth.

Definition.—A steam-engine is a machine by which the pressure of steam, due to its temperature, may be utilized in mechanical work. The term steam-engine is usually restricted to a motor in which a shaft is rotated directly or indirectly by the pressure of steam upon an alternating or a rotating piston fitting steam-tight, with as little friction as possible, in a cylindrical (or approximately cylindrical) case. A steam-engine may be employed to drive a line of shafting, to run one or more machines connected to its main shaft, to actuate a pump or a blower having its piston attached to its piston-rod, to propel a boat in which it is placed, or to move a vehicle on which it is mounted.

Classifications.—Steam-engines may be classified into horizontal, vertical, and inclined, according to the position in which the cross-head guides to the piston-rods are placed. But this classification, being merely structural, has theoretically little or no value. The oscillating engine has no cross-head, and consequently has no guides.

According to their use, engines may also be designated as stationary, semi-portable, portable, locomotive, locomobile (traction), marine, hoisting, or pumping engines, and steam fire-engines.

Engines whose pistons travel lengthwise in the cylinders, and which have a reciprocating motion, are called "rotative" or reciprocating engines, rotative being an arbitrary term practically meaning the same thing as "rotary," which term is applied to those engines wherein the piston (often called the "follower") rotates in the cylinder about its own axis and about the axis of the cylinder.

Engines may be further distinguished as "single-acting" if the steam works only on one side of their pistons, and "double-acting" if the steam is admitted first on one side and then on the other. They may be "single" or "duplex" respectively; single if there is but one cylinder working upon the shaft, and duplex if there are two cylinders which have exactly the same function. They may be "compound" if the exhaust from one or more of the cylinders enters one or more other cylinders, and "non-compound" if the exhaust discharges into the open air or into a condenser. If the exhaust is condensed by contact with a jet of cold water or with metallic surfaces cooled by a current of water, they are "condensing" engines, in contradistinction to those in which the exhaust is not condensed and which are known as "non-condensing" engines. They may have "fixed" or "variable" cut-off. If variable, they may be variable only by hand or "automatic," which variation may be effected by changes in the load or in the steam-pressure, or as this change must be made by hand. If adjustable, they may be variable while the engines are running or only when they are stopped. If automatic, they may be so by reason of the point of cut-off being changed, or by merely choking off the steam-supply so as to lessen it in case of decreased load or initial pressure. They may or may not have a beam. The cylinders may be fixed or oscillating.

When the piston consists, instead of a piston-rod acting upon a connecting-rod or directly upon a plunger or piston, of a "trunk" or hollow cylinder in which vibrates the connecting-rod attached directly to the piston, the construction is known as a "trunk" engine. If the trunk passes through a stuffing-box so that steam may be used upon the full area of the piston upon one side and upon a smaller area upon the other, it is a "half-trunk" engine. When the diameter of the cylinder equals the stroke of the piston, it is known as a "square" engine.

When the connecting-rod of a horizontal reciprocating-engine on the out-stroke passes under the line of the main shaft, the engine is said to be "under-running;" if it passes over the line of the main shaft on the out-stroke, it is "over-running." (A locomotive is under-running when moving ahead, and over-running when moving backward, because the cylinders are arranged with the piston-rod and cross-head behind them.) In an over-running horizontal engine, the top of the fly-wheel, when there is one, runs from the cylinder; in an under-running engine it runs toward the cylinder.

That end of the cylinder which is next the cross-head is called the "inner" end of any engine, the "front" end of any horizontal stationary engine, and the "crank" end if there be a crank. The end farthest from the cross-head is the "out" end in any engine, and the "back" end in any but a locomotive. The heads of a vertical engine having a crank may be designated either as the "crank" and the "out" end, or as the "upper" and the "lower" end.

Definitions of Parts.—Of the various parts of the steam-engine it may be well to name its principal pieces and functions in a running form. The steam from the boiler passes into and through the *supply-pipe*, in which there is placed a *stop-valve* and in which there should also be a *back stop-valve*. In an engine which throttles the steam or cuts off its supply in the pipe there is a *throttling-valve* worked by a *governor* or *regulator*. From the supply-pipe the steam passes in many engines into the *steam-chest*, in which there is placed a *valve*, generally in these cases a *slide-valve*, which may or may not be balanced for the purpose of making it work with a maximum of pressure and friction upon its seat. In some slide-valve engines there is a separate *cut-off valve* working upon the back of the *main valve* or upon a partition in the steam-chest. Many engines have no steam-chest proper, and many have no slide-valve, its place being taken (1) by a *rock-valve*, which is a slide-valve bent to a curve around an axis at right angles to its motion, instead of being flat upon its working side; (2) by a *piston-valve*, which is equivalent to a slide-valve wrapped around an axis parallel to its direction of motion; (3) by a *plug-valve*, which is practically a rock-valve having control of only one port and only one function instead of two ports and two functions; or (4) by a *poppet-valve*, which is a disc or a pair of discs fixed upon a stem, having motion parallel to that stem, and opening or closing a circular aperture for the passage of steam. The steam is admitted by the valves that open and

control the *ports*, which are the mouths of the *steam-passages* (also called *steam-ways*) into the *cylinder*, where it acts upon the *piston*. The ports and passages which admit the steam are called *induction*-ports and passages, the term *eduction* being applied to those used only to discharge steam which has been in the cylinder. The steam which has been used in the cylinder is termed *waste* or *exhaust* steam, and is discharged through the *exhaust-port* and *exhaust-pipe* either into the open air, or into another cylinder, or into a *condenser*, where it is condensed into hot water by the action of cold *circulating-water* or *injection-water*, constantly renewed by the *circulating-pump* or by a head from a tank, reservoir, or other source of pressure and flow. (In a locomotive the exhaust goes through a *blast-pipe*, whose end is called the *exhaust-nozzle*.) The ends of the cylinder are called *heads* or *covers*, in one of which there is a *stuffing-box* through which passes the *piston-rod*. The *lubricator* discharges into the steam-cylinder, or into the steam-chest, or into the steam-pipe near the steam-chest, its object being to lubricate the valves and piston. At each end of the cylinder there may be an automatic *escape-valve* or *blow-off cock* (also called *cylinder-cock*) for the discharge of water which may collect in the cylinder. The cylinder is usually covered with a *lagging*, purposely a poor conductor of heat. Sometimes its walls are double, and the space between, through which there is a circulation of live steam, or exhaust steam, or hot air, is called the *jacket*. Where there is a condenser the excess of air, which would otherwise mar the vacuum, is removed by the air-pump at the same time that the water of condensation is taken away, the reservoir which contains this water being called the *hot well*. Through the *blow-through valves* live steam is forced through pipes, chest, and cylinder (escaping by the *snifting-valve*) before the engine is started. The pressure in the condenser is measured by the *vacuum-gauge*. The *piston-rod* is usually attached to a *cross-head* generally working in or upon *guides*, which give a straight-line motion to the piston-rod and to the piston. The cross-head may, however, be given a true straight-line motion by *radius-rods* or *guide-bars*. In those engines in which the cylinders oscillate they swing upon *trunnions*. The reciprocations of the piston are communicated to the *crank* and *crank-shaft* by a *connecting-rod* in most other than beam-engines; sometimes a beam is interposed before the acting-rod. On the crank-shaft there is a *fly-wheel* which by its momentum equalizes the motion and tends to keep the engine steady, although the load and the pressure of the steam may vary. The valves are worked by the *valve-gear* or *valve mechanism*.

Action of Steam.—For a complete understanding of the operation of the modern engine it will be necessary to explain some of the more ordinary terms used to express details of the steam action. The entrance of the steam into the cylinder is usually given the name of *admission*, although engineers distinguish between the almost instantaneous admission which takes place (or should take place) before the piston has made any part of its stroke and that fuller admission which continues after the piston

has commenced its stroke, and while it is in communication with the steam in the chest. When communication is closed between the cylinder and the steam-chest, "cut-off" is said to have taken place; and from that point the next period is called "expansion." The point at which the exhaust-valve is opened and the expanding steam is allowed to enter the exhaust-passage (whether to go into another cylinder, into a condenser, or into the air) is called *release*, the operation which follows being *exhaust*. Just as admission may take place a trifle before the piston gets to the beginning of its stroke, so the exhaust may be released a trifle before stroke-end, the terms *pre-admission* and *pre-release* being used. The closing of the exhaust-valve, so as to confine what is left of the exhaust steam in the cylinder between the advancing piston and the cylinder-head, is called *exhaust-closure*, the result being "cushion" or "compression;" and this exhaust-closure is generally made to take place earlier in high-speed engines than in those which run slower, the compressed steam acting as a cushion to absorb the momentum of the reciprocating parts and to prevent jarring and racking of the engine. Cushioning also has the effect of heating the compressed steam and the walls of the cylinder and passages in communication with such compressed steam, this being of advantage in preventing the chilling of the new "live" steam which is admitted when "admission" takes place.

Cylinder and Piston.—The most essential points of a reciprocating engine are the cylinder and the piston, with the distributing-valves. In a rotary engine the cylinder is replaced either by a cylinder having a rotating piston or by a case containing two gear-wheels meshing together. A reciprocating engine is usually built with one or more distributing-valves, and these are most frequently put in a steam-chest, but many high-grade engines have no steam-chest, and it is possible to construct reciprocating engines which use the piston-head as the distributing-valve. The piston may be said to consist of the "head" (that circular portion which fits in the cylinder) and the "rod;" and the head generally consists of a "spider" attached to the rod and a "follower" plate attached to the spider. There are often packing-rings which serve to make a steam-tight joint between the piston-head and the cylinder-bore, and these rings may be steam-packed—that is, driven out by the action of the steam-pressure (communication being permitted by orifices contrived for that purpose)—or they may be spring-packed, in which case they are held out by the pressure of springs (generally German silver or similar metal, as steel loses its temper under the high temperature of most steam-cylinders) between them and the rim of the spider. The piston-rod may be screwed into the head, or passed through and riveted, or passed through and kept by a nut from being pulled out, or passed through and keyed in; or combinations of these methods may be employed.

Steam-chests.—In a horizontal engine the steam-chest (where there is one) may be above, on the side, or below the cylinder, and in a vertical or an inclined engine may occupy the same relative positions. A chest placed

below the cylinder of a horizontal engine has the advantage of permitting the steam which may be condensed in the cylinder, or the water which may be carried over into it, to be drained out through the exhaust-passages without accumulating in sufficient quantity to cause damage to the cylinder-heads or the piston. Where the steam-chest is upon the side, this advantage is possessed only in part, and when above, not at all.

Valves.—As to the valves themselves, which effect the steam distribution, a detailed study of which is necessary to a thorough understanding of steam-engine design, construction, and operation, they may be (1) flat slides; (2) cylindrical slides, each of these having a movement lengthwise of the cylinder; (3) cylindrical oscillating (or "rock") valves, having a motion about an axis at right angles to that of the engine-cylinder, but controlling the ports in the same way as the slide; (4) plugs which oscillate about an axis at right angles to that of the engine-cylinder, but each controlling but one port; or (5) poppets (sometimes written "puppets," and also called "beat-valves"), which are circular discs that open and close circular ports by rising and falling.

D-slide Valve.—The operation of the ordinary D-valve in steam distribution and its effect upon the piston position are exhibited in Figures 11 and 12 (*pl.* 80), where No. I. shows the piston at about the centre of the down stroke, with the slide-valve admitting live steam from the chest above the piston, and opening communication between the lower end-port *g* of the cylinder and the exhaust-passage *o*. The valve is moving upward or in the direction opposite to that of the piston. A little later, when the piston has gone lower, the upper edge of the valve will begin to cut off steam from entering the port *d*, and during the up-stroke the lower end-port will begin to close by the advancing inner edge of the valve. No. II. shows the piston at about the middle of its up-stroke, the valve moving downward. The live steam is here entering the lower passage *g* through the end-port *f*, while the upper passage *e* is in communication with the exhaust by the upper end-port *c*, the arch *d* of the valve, and the exhaust-port and passage *d*.

Oscillating or Rock-valve.—The so-called "oscillating" or "rock-valve," controlling two end-ports and an exhaust-port, is a development of the flat slide, but the objection to this form is that it wears to an arc of shorter radius, while its seat wears to one of a larger radius, so that its tightness cannot be maintained.

Piston-valve.—A modification of the flat slide is the piston-valve, a cylinder moving lengthwise of the engine, and so ported as to act, as regards distribution, exactly like a flat slide, its advantage being that it is not pressed to its seat by the steam in the chest, as in the case of the flat slide, although many consider that this advantage is offset by the difficulty of keeping it tight.

The three-port slide, commonly called the "D-valve," and its equivalents the rock- and the piston-valve, have the merit of extreme simplicity, but their steam distribution, which will be explained farther on, is

defective. An improvement gives the exhaust a separate valve or valves, with time of opening or closing not dependent upon load or point of cut-off, while the admission and cut-off are effected by another and a separate valve or valves.

The flat slide, the piston-valve, and the oscillating valve never escape from the control of the driving-mechanism; the poppet is usually closed by its own weight or by a spring; and of the "plug" type, those used for admission only are generally opened by positive means and closed by a spring or a weight, while those employed for exhaust alone or for both admission and exhaust are never released from the driving-mechanism. Figure 1 (*pl.* 83) shows a double-seat poppet-valve.

The slide-valve may be wholly or partially "balanced"—that is, relieved from the pressure of the steam in the chest—by a plate or ring playing against the lid of the chest, and thus lessening the area upon which unbalanced pressure may be exerted. Most stationary and all locomotive engines employ the slide. The oscillating or "rock" type is used on a few stationary, the "plug" on high-grade automatic cut-off stationary, and the "poppet" principally on the better class of marine engines, although some recent stationary engines, like many of the old beam-engines, employ poppets. The piston type is used very largely on direct-acting steam-pumps, and is slowly coming into favor for small marine engines. There may be in double-acting engines but two cylinder-ports, one for each end, each acting alternately for admission and exhaust; or there may be two for admission and two for exhaust. Where there are four ports, those for the exhaust may be controlled by the same kind of valves as those for admission, or by a different kind.

Meyer's Variable Cut-off Slide-valve.—Figure 2 shows a variable cut-off valve-motion (Meyer's); the upper valve is moved by an eccentric-rod, but it is placed directly upon the back of a three-port slide-valve, also operated by an eccentric-rod. The time at which live steam is cut off by the upper valve (earlier or later according as the load on the engine is light or heavy) is varied by moving the two parts of the upper valve farther apart or closer together by a right- and a left-hand screw operated by hand as may be desired by the engineer. A throttling governor might be used with this movement to make the engine automatic under varying loads and pressures; but the Meyer valve is usually employed where there are no sudden changes either in load or in pressure.

Farcot's Slide-valve.—Figure 3 (*pl.* 82) shows the successive stages of distribution by the Farcot slide-valve motion, in which a riding cut-off valve is actuated through a cam (f) by the governor. At *I* the live steam has been cut off by the main valve from the left-hand end-port d^1, while the right-hand end-port d is also closed by the same valve as an exhaust-port. The position of the cut-off valve is therefore immaterial. In *II* the right-hand end-port d of the seat and the end-port of the main valve are open to live steam, and the left-hand end-port d^1 of the seat is partly open for exhaust. In *III*, although the passages b and d are in communi-

cation, the right-hand end-port is closed to live steam by the action of the end c of the cut-off plate worked by the cam f. The left-hand end-port d^1 is exhausting. In IV the valve has commenced to move to the right, but while the left-hand end-port d^1 is still in exhaust communication with the exhaust passage o through the valve-arch a, the right-hand passages b and d are still closed by c to live steam. In V the end c^1 of the cut-off plate has uncovered the left-hand end-passage b^1, so that live steam can enter it, but the main valve has not yet opened the left-hand end-port d^1 to live steam, although it has closed the right-hand end-port d. This is an automatic cut-off system.

George Distributing-valve.—The George distributing system (*pl.* 83, *fig.* 3) has a plate consisting of two parts placed one above the other, and arranged between a three-port slide-valve and an expansion-valve which is moved by a special eccentric-rod. This double plate divides the steam-chest, as in Figure 4, into two portions communicating by ports which can be closed by the upper valve. The time of cut-off (consequently the degree of expansion) can be changed by displacing the two central portions of the upper part of the plate by a rack and a cog-wheel, the cog-wheel being movable by a rod passing through the steam-chest cover. The main valve, which serves solely for admission and exhaust, works steam-tight both upon the main valve-seat and against the lower side of the partition. As shown, this becomes an automatic cut-off system when the eccentric operating the upper valve has its position on the shaft changed angularly, or the amount of its throw varied, by a governor.

Gonzenbach Valve.—Figure 4 shows the Gonzenbach valve. The ordinary three-ported slide A gets its reciprocating motion on the valve-seat B through an eccentric-rod which puts first one and then the other of the end-ports in communication with the steam in the steam-chest, while the third port is placed in communication with the exhaust opening through which the steam passes into the air or into a condenser. The upper valve E, which is in a separate steam-chest (C) and is also moved by an eccentric-rod, permits "live" steam from the boiler to go through the orifice D, but as soon as D is closed the steam is worked by expansion only. If the upper valve has constant travel, this type will require a throttling governor to make it automatic under varying loads and pressures, but if the eccentric throw or its position on the shaft is varied by the governor, the whole becomes an automatic cut-off system.

Poppet-valves.—In the Collmann poppet-valve system there are independent exhaust-valves placed below, one for each end, and the so-called "steam-valves" which control the admission are placed on top, one at each end, being opened by eccentrics at regular intervals and closed at variable times by a trip-motion controlled by the governor. Figure 11 gives the details of the Sulzer poppet-valve motion. The exhaust-valves below and the admission-valves above are all poppets, and are opened at fixed times by eccentric-rods. Each exhaust-valve has a fixed time of closure, but the admission by each steam-valve is cut off by a

spring at periods determined by the position of the governor, tendency to increase of speed in the engine causing earlier cut off. In the Nolet valve system the exhausts are below, by means of a slide-valve at each end, with fixed periods of opening and closing; admission is at the side by poppets (one at each end) which have a fixed time of opening, but which are dropped by the influence of a weight at variable times determined by the position of a centrifugal governor.

Figures 6 to 9 (*pl.* 83) show details of the valve-motion of oscillating engines. Figure 10 represents the Meyer throttling-valve motion, which controls the passage into the steam-chest by a conical valve, whose times of opening and closing are controlled by a stem bearing a yoke operated by a revolving double cam, which is raised and lowered, according to the position of the governor, earlier or later in the stroke.

Valve-operating Mechanisms.—The valves may be operated (1) by a beam, (2) by one or more eccentrics or cranks on the main shaft, (3) from the connecting-rod, (4) by the piston-rod or the cross-head, (5) through a shaft driven by gears from the main shaft, (6) by toes on a rock-shaft worked by a beam, or (7) by cams giving a positive motion. The eccentric-rod may be attached directly to the valve-stem or to a crank-arm fastened thereto, or to a rocker-arm connected therewith, or it may drive through a so-called "link," which may be connected to the valve-stem or to a rocker-arm. The eccentric is practically a crank-pin so enlarged as to embrace the shaft. In all motions where a rotating shaft drives a reciprocating member, it acts exactly as does the crank, while dispensing with the necessity of cutting or bending the shaft, and permitting of its eccentricity being increased or diminished and its position on the shaft being varied by rotation; but it is not available for driving a rotating shaft from a reciprocating part.

Where there is an oscillating link it may have a fixed centre of oscillation and a sliding block, by varying the position of which the amount of travel of the valve may be altered; or the same effect may be produced by varying the point of suspension of the link. The link may be either curved or straight, and if straight its convexity may be turned either toward or from the eccentric. Usually the amount of variation of the motion of the link or of the block is sufficient to give the valve movements, varying from a maximum in the direction which will drive the engine forward to a maximum in the direction which will run it backward, there being an intermediate point at which the motion of the eccentric produces no motion in the valve. Most eccentric-and-link engines are thus reversible, this being essential in locomotive and marine practice and for hoisting-engines. Reversal may also be accomplished (1) by throwing the eccentric around on the main shaft, so that it shall follow, instead of preceding, the crank, or (2) by sliding it across the shaft to reach the same position and to produce the same result.

The peculiar advantage of the eccentric-and-link valve-gear is not only its reversibility while the engine is running, but also its affording a wider

range of valve travel and consequently of expansion ratio. The block may either slide in a parallel slot in the link or embrace it and slide over it, the different constructions producing, other things being equal, the same valve-motion. In nearly all reciprocating engines the valve-movement is effected by means of an eccentric or its equivalent upon the driving shaft. This introduces irregularities of motion, which increase with the comparative shortness of the eccentric-rod, and are of the same class as those caused by the angularity of the connecting-rod. There is, moreover, considerable friction between the eccentric-sheave and its encircling strap.

An excellent class of valve-motion, and one which has already been largely introduced in marine engines and has made a good record in locomotive work, is that in which the valves are moved by lever-connections with the connecting-rod. Of this class the Joy valve-motion appears to be the best known and to have the best record.

The walking-beam was a great convenience in working the valves and the air-pump, as well as in making connections with the water-pumping machinery which constituted the only loads that were at first applied to steam-engines, and it was also a great convenience in paddle-wheel steamboats, where the high position of the shaft above the water-level demanded that the engines should sit low; but the necessity of having the shaft below the water-level, as in propeller engines, led in most cases to its abandonment, although it is still employed in certain classes of marine work (ferryboats, etc.), and, notwithstanding the large amount of room which it takes up, it is still used on large stationary engines in Europe. But the air-pump and feed-pump are worked by eccentrics quite as well as they formerly were by the beam, and now, in many cases, the air-pump is operated by an independent motor.

The Cut-off.—It is now thoroughly understood that, as discovered by Watt, steam does the most possible work (other things being equal) when it leaves the engine at the lowest pressure—that is, when the terminal pressure is least compared with the initial; it is therefore desirable to "cut-off" after the piston has been started, so that its expansion from a high tension to a low one shall impel the piston, the release of the expanding steam being effected at the end of the stroke, or slightly before it in order to permit a free exhaust.

The point at which cut-off is effected may be varied in two ways: by the hand of the engineer or by the governor of the engine. The first is practicable for marine and locomotive but not for stationary engines. Cutting off the steam has the double advantage of working it (in most cases) more economically and of proportioning the force exerted and the steam expended to the load. The fly-wheel of course aids greatly in a regular motion, but, leaving out of consideration the question of economy of steam-consumption, it would be an absurdity to keep on storing up power until there was more than the fly-wheel could absorb, or to let the amount thus stored run down to near that point at which there would not be enough left to supply the demand for power. Besides this, the fly-wheel

can take care only of temporary and short-lived irregularities. Variations of load may be provided for by choking off the steam-supply either by hand, as in marine and locomotive engines, or by a governor, as in those which are stationary or so-called "portable." But this choking or throttling, while an efficient means of taking care of load variations, uses the steam very wastefully (without proper expansion) under heavy loads, when there is the most steam needed and used.

The Drop Cut-off (also known as the Sickels cut-off, and claimed by both Sickels and Hogg) was introduced about 1841. It consisted of a set of steam-valves, each raised by a catch which could be thrown out at the proper moment by a wedge so adjusted that it would drop the valve at any desired point in the earlier half-stroke. Later, this was improved by the addition of a "wiper" having a motion at right angles to that of the valve and its catch, by giving to this wiper a motion in the direction coincident with the piston. This enabled the cut-off to be effected at any point in the stroke. For stationary engines this detaching was made automatic, depending upon the action and position of the governor. The action of the governor to determine the cut-off had been made in 1834 by Allen, who had a cut-off valve separate from the main valve. In 1849, Corliss attached the governor to a drop cut-off, and in 1855, Greene produced an engine which had the advantages of plain slide-valves at all ports, a range of cut-off from zero to full stroke, and automatic action of the governor to effect cut-off. In Wright's engine the governor operates cams which hold the valves open a longer or a shorter time, according to the speed, cutting off the steam earlier when the speed tends to grow too high, and *vice versâ*.

The Governor.—The automatic device used to control either the throttle or the point of cut-off is called a "governor." Its most common form, the centrifugal fly-ball type (*pl.* 82, *fig.* 5), was invented by Watt.

Farcot Centrifugal Governor.—In the Farcot centrifugal governor, shown in Figure 15 (*pl.* 83), there are connected with the extended shaft of a conical pendulum (driven by a horizontal shaft seen below) two friction plates. Between these there is a pair of conical wheels which engage with the upper or the lower of these friction plates according to the increase or decrease in the engine speed, moving the conical wheels to the left or to the right as the case may be. The conical wheel of the upper horizontal shaft gearing into these conical wheels is, together with the shaft, moved to the left or to the right, and moves by a screw in one or the other direction the spindle of the expansion-valve. When the conical pendulum is in its normal position by reason of the engine speed and its own being normal, neither of the friction plates is disengaged.

Allen Governor.—Figures 12 and 13 show the Allen governor, in which there is a paddle-wheel in a corrugated cylinder filled with oil (*fig.* 13). Increase of engine speed tends to turn the cylinder faster about the wheel, and by means of a segment gear this motion is made to move the cut-off to an earlier point.

Buckeye Governor.—There are very many successful engines in which there is a centrifugal governor upon the main shaft; a variation in the rotation speed, due to change of load or of initial pressure, causes the weights to approach or recede from the centre, and the levers to which they are attached to vary the angle which the eccentric makes with the crank, or its amount of eccentricity, thus varying the point of cut-off, and in many of these engines other functions, such as the times of steam admission and exhaust opening, and the point at which the exhaust is closed. Of this "Hartnell" type the "Buckeye" is the best known (*pl.* 83, *fig.* 16).

Ball's Regulator.—There are regulators by which the amount of throttling or the earliness of cut-off is controlled in proportion to the load and not to the speed, as in the Ball engine, the governor of which is shown in Figure 14.

Rotary Engines, while having the advantage of being able to run with great speed and with little jar, cannot very well work steam expansively. The difficulty of keeping them tight is due to the fact that friction is proportionate to the speed of the wearing surfaces, and the exterior of a revolving circle must of necessity travel faster than portions nearer the centre. Hence it is almost impossible to keep the ends of such rotating cylindrical pistons or "followers" packed. The extreme simplicity of such engines, and the convenience with which they may be used for "direct-driving" high-speed machinery, such as circular saws, would make them very popular if they were not so wasteful of steam and so difficult to pack. Figures 5 and 6 (*pl.* 85) show Kenyon's rotary engine, in which the steam is admitted and permitted to exhaust by a slide-valve. As shown in Figure 6, it is exhausting from the left-hand side and taking steam at the right; the direction of motion being contrary to that of the hands of a watch. In Figure 1 is shown Runkel's rotary engine, in which a rotating piston or follower is made to turn a crank, thus combining all the disadvantages of both the reciprocating and the rotary type. Figure 2 (*pl.* 84) shows Turner's; Figure 3, Cox's; Figure 7 (*pl.* 85), Hall's; and Figure 2, Borries' rotary engines.

Marine Engines are for the most part vertical, and are generally what are known as "inverted"—that is, the cross-head is below the cylinder unless there is a beam. Marine service necessitates high economy of steam, hence compounding and condensing are carried to the utmost possible grade of perfection. The modern ocean steamer requires from 5000 to 20,000 indicated horse-power to propel her 5000 to 15,000 tons' burden at speeds which, while increasing almost with each successive high-grade vessel, now reach the average rate of 20 knots or $23\frac{1}{10}$ statute miles per hour between Queenstown and Sandy Hook.

Oscillating Steam-engines.—The oscillating type of steam-engine was suggested by Trevithick, and is the best for ordinary paddle-wheel vessels, as it is light and compact and has the fewest working parts. It will work with the cylinder in any position from horizontal to vertical, although best in the latter position. It does not, however, admit of very early cut-

off, and the trunnion is apt to leak. In Westland's oscillating engine, shown in Figure 5 (*pl.* 84), while the crank rotates the cylinder oscillates on trunnions. There are on top of the cylinder four valves, worked by a rock-shaft placed in the centre of the cylinder's length and having tappets which catch in bell-cranks moving the valves. Figure 1 represents the Mackintosh type. The steam is admitted through the trunnions or pivots upon which the cylinder oscillates. In this type the fly-wheel shaft is below and the cylinder oscillates above it; in Figure 4 (the Hicks) the fly-wheel is above; and in Figure 3 (*pl.* 85; Fèvre's) the oscillating axes are on the bottom instead of at the centre of the cylinder. Figure 4 shows the Root oscillator.

Penn's Trunk Engine.—In the trunk type of steam-engine (*pl.* 86, *fig.* 1) there is no piston-rod, the connecting-rod being hinged to a pin in the centre of the piston, which is surrounded by a cylindrical case or "trunk" concentric with the cylinder and continued out at its other end, so that there are the same effective piston-areas back and front. This is the lightest and most compact of all marine screw-engines; but the friction of the stuffing-boxes for the trunks is excessive, and the bearings of the pin in the piston are liable to become heated, and are then difficult to cool, besides which the side-cylinder wear is very great, particularly in running astern.

Beam-engines are those in which the shaft receives its rotary motion through the intermediation of a lever either above or at the side of the cylinders. Ordinarily the expression "beam-engine" refers to one in which the "walking-beam" or "working-beam" is above, the other types being generally spoken of as "side-lever" engines. Beam-engines are now but little used, except for marine purposes, although at one time they were the only type, and later on the most common one, for stationary engines; in fact, the beam was used in early locomotives. (See Vol. V., p. 173.)

When used aboard ship, a beam-engine requires a higher deck than is given to it in other countries than the United States.

The American Beam-engine for river-steamers was first designed in 1822 by Robert L. Stevens. Its great advantage is its flexibility, permitting long vessels to spring without crippling the engine. It works smoothly, and is economical and compact.

The Mississippi River steamboat constitutes a type of marine construction deserving special mention; but its peculiarities are so dependent upon the construction of the hull which it drives that its consideration will be deferred for the Volume on Marine Architecture. The North River and Long Island Sound steamboats are in themselves a special variety to be found in no other country and in no other section of the United States.

The Side-lever Engine is of two kinds: (1) that in which the fulcrum is between the connecting-rod and the side-rods from the piston-rod cross-heads, as in Figure 3 (*pl.* 86); and (2) that in which the fulcrum is at one end, as in Figure 2. The first is the true side-lever type, the second being often called the "grasshopper" engine. This type is especially

adapted for marine purposes by reason of its simplicity, cheapness, capability of giving a long stroke in a shallow ship, comparative freedom from racking, and absence of a dead point even where there is but a single cylinder. It will run when in a state of repair under conditions which would disable any other type.

The Steeple Engine of Trevithick has the piston operating directly upon the crank; it is compact, light, and cheap, and has fewer working parts than the side-lever type, but requires a deep ship and needs two piston-rods, between which the shaft is placed. This engine, so modified as to lie horizontally, is well adapted for war-ships, in which the machinery must be low down in the hull. This modification is often known as the "return-connecting-rod" type.

The Return-connecting-rod Engine, in very general use for marine purposes, has the connecting-rod on the side of the crank-shaft opposite to the cylinder, and there are two piston-rods, one above and the other below the crank. This allows of very long stroke, but limits the diameter of the piston, makes packing the stuffing-boxes difficult, and allows of but very short eccentric-rods, unless they are placed on the same side as the connecting-rod.

The Condenser.—In the theoretically perfect steam-engine the steam should be discharged at a pressure corresponding to absolute zero and at the temperature of the external air. The nearest approach to these points that can be obtained, consistent with other desirable features, the better. A device which would so condense the steam as to remove all pressure from the exhaust side of the piston would be very advantageous. The earliest attempt in this line effected this condensation in the cylinder itself by a jet of cold water, the unbalanced atmospheric pressure alone being the motive power (see p. 246). The use of the working cylinder as a condensing vessel having the disadvantage of cooling the entering steam before it had done any work, the employment of a separate condenser, due to Watt, has been found necessary; but the methods of effecting condensation in a separate vessel are various. A jet from a plain tube or from a "rose" may be employed; or the steam-exhaust may be made to circulate against surfaces cooled by currents of cold water; and such surfaces may be either flat metal partitions or tubes containing the cooling liquid.

Surface-condenser.—Figure 7 (*pl.* 79) shows in section and in perspective an improved surface-condenser combined with an independent air-pump and a circulating-pump. The exhaust steam entering from the engine at *A* is scattered to the perforated plate *O*; it expands in the upper part of the case, then passes among the tubes, and leaves the case at *B*, going thence to the air-pump. The cooling water entering the circulating-pump passes into the compartment *F*, thence into the small tubes, which it traverses, then returns through the annular spaces between the wall and the large tubes, and empties into the compartment *G*. Thence it passes into the compartment *H* by the passage-way *E*. It next circu-

lates through the upper section of the condenser in the same way, and finally passes out through *D*. This type of condenser differs essentially from others in that it employs concentric tubes, and that each tube is free to expand and contract without requiring any ferules or special joints. It has extraordinary capacity and is very readily cleaned. Tests with a small experimental apparatus show 101.8 pounds of steam condensed per hour per square foot of condensing surface with vacuum, and 204.2 pounds without. In the first case the injection-water temperature was 56½° Fahr., discharge 98°, hot well 138°, and average vacuum by the gauge 24½ inches. In the second the injection was 78½°, discharge 139°, and hot well 201°.

The old jet-condenser has been transformed into what is now known as the siphon-condenser (*pl.* 79, *fig.* 4), in which no pump is necessary; the vacuum produced by the condensation of the steam by a jet being sufficient to raise the water in a continuous current when the action of the apparatus is established.

It should be distinctly understood that a condensing engine may be either compound or non-compound, single or duplex, and that the air-pump and circulating-pump of the condenser may be so arranged that they may be either driven by the main engine itself or operated as separate pieces of mechanism. It is well to have the condenser so attached that it may be thrown out if it be desired to inspect, clean, or repair it, or if it be found that the engine is underloaded. Examples of non-compound condensing engines are given in Figures 4 and 6 (*pl.* 82); of compound condensing in Figures 3 and 4 (*pl.* 81); and of triple-expansion condensing in Figure 4 (*pl.* 88).

Compounding.—There being in a very early cut-off and in an excessive amount of expansion in one cylinder certain disadvantages—for example, the chilling of the internal surfaces of the cylinder and passages by the low temperature of a low-pressure exhaust, and the great range of pressures upon the piston and crank-pin during a single stroke—these disadvantages are lessened by what is known as "compounding;" that is, running one or more engines with the exhaust from another engine, thus requiring only a moderate degree of expansion in the first cylinder, and running the second cylinder by expansion only, both engines being connected with the same crank-shaft, or, in the case of those direct-acting pumping-engines which have no crank, with the same pump-plunger. There may be between the high- and the low-pressure cylinder either direct communication by steam-passages or a receiver or intermediate vessel which permits the low-pressure piston or pistons to act upon the crank-shaft at right angles to the high-pressure cylinder.

Wolff Compound Engine.—In the Wolff or receiver compound engine the cranks are at right angles, so that they pass through dead-points at different times. The steam from the small or high-pressure cylinder passes into the receiver before going into the large or low-pressure cylinder; the pressures being thus equalized, although there is some loss caused by con-

densation of steam in the receiver. The condenser, with air-pump and feed-pump moved by a rock-shaft, is on the front. (It should be noted in this connection that the Wolff compound engine has a receiver; the Woolf compound has none.) In Figure 4 (*pl.* 81) is represented Woolf's compound beam-engine. Figure 3 (*pl.* 88) shows a Collmann compound engine in which the cranks are at right angles. Figure 4 shows a compound engine on Woolf's plan, but there are one high-pressure cylinder and two low-pressure cylinders, which have equal functions.

Double-cylinder Engines.—In the Woolf or receiverless compound engine the small or high-pressure and the large or low-pressure cylinder stand side by side under the same end of the beam, their pistons moving in the same direction at the same time; the exhaust passing from either end of the small to the opposite end of the large cylinder. McNaught's improvement has the cylinders at opposite ends of the beam, the pistons moving different ways, and the steam passing from either end of the small cylinder to the nearest end of the large one. Elder's compound engine has the large and the small cylinder side by side in close contact, inclined at 45°; pistons moving oppositely and driving cranks projecting in opposite directions from the shaft; a similar pair of cylinders acting on the same pair of cranks and inclined the opposite way at the same angle. Craddock's compound type has the cylinders side by side, their pistons driving cranks nearly opposite and moving for the greater part of the course in the same direction; the stroke of the small piston being made a little in advance of that of the large one, to prevent stopping on the dead points.

Concentric cylinders were employed by Rowan, the steam being admitted into a small cylinder and expansion continued in the larger one which surrounded it; the outer piston being ring-shaped, and having two rods fastened to the same cross-head as that of the inner one.

In the end-to-end double-cylinder type the steam commences its action in one end of a small cylinder, and completes it in the opposite end of a large one, the piston being attached to one rod. The space between the two pistons communicates with the condenser and is at all times a partial vacuum. In Garrett's double-piston engine the steam commences its action in one end of the cylinder and finishes its expansion in the opposite end, the former end having its capacity diminished by a plunger of large diameter passing through a stuffing-box and having one end fixed to the piston.

Treble-cylinder Engines.—In Elder's treble-cylinder compound the piston of the small cylinder drives one crank, and those of the two lateral large or low-pressure cylinders work a pair of cranks pointing in a direction opposite to the middle one. Rowan's treble-cylinder engine has the rods of the small piston and of the two large lateral pistons attached to one cross-head.

Triple and Quadruple Expansion.—Compounding is also accomplished in three or even four cylinders or sets of cylinders working successively. Where there are three grades of expansion the system is said to be triple

(or treble) expansion, irrespective of the number of cylinders employed. The cylinders may be placed in the same vertical axis or may be arranged side by side. Where there are more they may be arranged in pairs, in threes, or in fours, respectively side by side.

Triple-expansion Engines.—The cylinders of triple-expansion engines may be either three, four, five, or six in number. One arrangement is for the "intermediate" to be under the high-pressure and alongside the low-pressure cylinder; another, for the low-pressure cylinder to be under the high-pressure cylinder and beside the "intermediate;" or all three may be in line. There may be two cylinders for high pressure, one over the "intermediate" and the other over the low-pressure cylinder, or there may be two low-pressure cylinders beside each other, one with the high-pressure cylinder over it and the other with the "intermediate." There may be two high-pressure cylinders, each over a low-pressure cylinder, which latter have the "intermediate" between them, or there may be three low-pressure cylinders, side by side, having one high-pressure cylinder and two "intermediate" above them. A very convenient, although in some respects complicated, arrangement is that by which the steam may be worked through all three cylinders of a triple-compound engine with successive expansions; or two of the cylinders may be worked high pressure and one low pressure; or two cylinders may be worked at the same degree of expansion at low pressure and the other at high pressure; or all three may be worked high pressure; or any one or any two may be thrown out altogether. Triple-expansion engines have proved more economical than the ordinary compound, the fuel consumption being about twenty-five per cent. less. This is very largely due to the higher steam-pressure. Their wear and tear is rather less when three cranks are employed than where there are but two, as in the ordinary compound.

Figures 4 and 5 (*pl.* 86) illustrate a set of triple-expansion marine engines of eighteen hundred horse-power (indicated), constructed by Cravero & Co., of Genoa, Italy. To economize space the three valves are placed behind the cylinders, and are worked by levers from ordinary link motions. The cylinders are perfectly free among themselves, to the end that they may expand and contract without restraint.

The following are the principal dimensions, which are given because such engines are not very common, and their proportions are not familiar even to professional engineers:

Engines:	
Diameter of high pressure cylinder	26 in.
" " intermediate "	42.5 "
" " low pressure "	70 "
Stroke of pistons	43.2 "
Revolutions per minute	70
Piston speed	504 ft.
Proportions of cylinders: high : intermediate	1 : 2.67
Proportions of cylinders: intermediate : low	1 : 2.70
Proportions of cylinders: high : low	1 : 7.2
Order of cranks: high, low, intermediate.	
Indicated horse-power: high	602
" " intermediate	612
" " low	627
" " total	1841
Diameter of steel crank shaft	12.6 in.
" " propeller shaft	11.4 "

Condenser:		Stroke	27.5 in.
Number of tubes	888	Proportion between volume of pump and volume of low-pressure cylinder	1 : 9
Diameter of tubes	.87 in.		
Useful length	14 ft. 5 in.		
Total cooling surface	2906 ft.	*Circulating pump (single-acting):*	
Total cooling surface per indicated horse-power	1.56 sq. ft.	Diameter	15.75 in.
		Stroke	27.5 "
Air-pump (single-acting):		Volume swept per horse-power and per hour	6.2 cub. ft.
Diameter	24.8 in.		

Inverted-cylinder Triple-expansion Marine Engine.—Figures 1 and 2 (*pl.* 87) show a very recent example of a triple-expansion engine constructed for the screw steamer "Ivy." The engines are of the ordinary inverted-cylinder marine type, with three cranks, and are designed for an initial working pressure of 160 pounds per square inch in the high-pressure cylinder. The high-pressure, intermediate, and low-pressure cylinders are respectively 16½, 26, and 44 inches in diameter, and their common stroke is 36 inches. The high-pressure cylinder has a piston-valve, and the others have ordinary slides. The valve-gear consists of double eccentrics and double-bar link-motion. The cranks are of forged iron 8½ inches in diameter in the body, and their pins are 8½ inches in diameter and 9 inches long. The piston-rods are 4 inches in diameter; the connecting-rods are 6 feet long and 4 inches in minimum diameter. The condenser is of the "surface" type and has 800 square feet of cooling surface.

The Four-cylinder Triple-expansion Engine shown on Plate 88 (*fig.* 2) has the cylinders disposed in pairs, tandem fashion, the two next the crank-shaft being the high-pressure and the intermediate cylinders respectively, while the two rear cylinders are low-pressure and are of unequal diameter. It is in this inequality of diameter that one of the peculiarities of the engine consists. By this arrangement there are obtained two engines, either of which could be worked as an independent tandem-compound engine in case of accident, or which could be worked coupled as tandem compounds (there being then two high- and two low-pressure cylinders), in case of circumstances necessitating a reduction of boiler-pressure below that suitable for the triple-expansion system of working. The engine is thus available for working in three different ways, the necessary changes being made by the arrangement of pipes and valves connecting the cylinders. The arrangement is also one which could be advantageously adopted for converting a tandem-compound engine into the triple-expansion system.

In the engine illustrated the diameters of the cylinders are as follows: high-pressure, 11.02 inches; intermediate, 15.75 inches; and low-pressures, 20.08 inches and 35.43 inches. The stroke is 35.43 inches. The engine, running at seventy revolutions per minute with steam at an initial pressure of one hundred and fifty pounds per square inch absolute, cut-off at from 40 to 50 per cent. in the first cylinder, will indicate three hundred horse-power.

In proportioning the cylinders of the engine it has been deemed of less

importance to attain equality of power in the two halves of the engine than to secure as small a variation as possible from what is known as "the mean turning moment," it being of special importance for mill purposes to obtain the steadiest possible driving.

Only the high-pressure and intermediate cylinders are steam-jacketed. The front and rear cylinders of each pair are connected by three bolts passing through cast-iron distance-pieces. This arrangement makes a firm connection, and at the same time affords facilities for the examination of the stuffing-boxes, etc. The steam- and exhaust-valves are of the Corliss type. The exhaust-valves are nearest to the ends of each cylinder, and are so placed that they drain the latter. The steam-valves are driven from one side and the exhaust-valves from the other side of each engine, this simplifying the disposition of the parts and rendering them more accessible. The steam-valves on the high-pressure cylinder are fitted with a trip cut-off gear controlled by the governor, which member actuates a rod carrying cams with serrated faces, the point of the stroke at which the detent is released depending upon those parts of these cams that act upon the releasing rods. Each rod operating the detent gear has a hardened steel chisel-shaped point, which comes into contact with the cam as the valve is opened by the action of the eccentric, the further movement due to the eccentric, after the detaching rod has been stopped by the cam, causing the rod to actuate the detent, and, by releasing the valve from the pull of the eccentric, to leave it free to be closed by the action of a spring. This gear has the advantage of throwing exceedingly little work on the governor, the contact of the points of the releasing-rods with the cams being merely momentary. The bed-plate is made with a long foot under the crank-shaft bearing, this foot being extended toward the guides to prevent twisting of the bed under the action of the connecting-rod on the cross-head. There are two vertical air-pumps, which are driven from the cross-heads through bell-crank levers.

Twin Triple-compound Engine.—Figure 4 (*pl.* 88) shows a twin triple-compound engine arranged to drive the screw of a vessel. Of the six cylinders, each has its separate supply of steam, but all work upon the same shaft. The large cylindrical vessel seen in front is a surface condenser—that is, one in which the steam is condensed by contact with metal surfaces cooled on the outer side by a current of water, and not, as in Watt's condenser, by the direct action of a jet of water.

Quadruple-expansion Engines may have from four to eight cylinders. The most common arrangements are—(1) where the high-pressure is above the low-pressure cylinder, the first intermediate beside the high-pressure cylinder, and the second under this and beside the low-pressure; (2) where the high-pressure is above one low-pressure cylinder, with two "first intermediates" beside it, and a "second intermediate" below one of the first intermediates and between the two low.

Quadruple Disconnective Non-condensing Land-engine.—A good example of a quadruple engine is shown on Plate 89. While this style

is intended for stationary purposes, it embodies many features of marine engines, as, for instance, double web-cranks instead of the usual overhung single cranks, and connecting-rods with T-ends for the crank-pin bushes. The cylinders are unjacketed and are covered with non-conducting material and lagged with polished teak; they are 12 inches, 16 inches, 22 inches, and 28 inches in diameter respectively, all having a piston stroke of 36 inches. Each pair is bolted to a bedplate of box section, with planed seats for the cylinders and pedestals. These latter are four in number, strongly bolted to the bedplates and adjustable by wedges. They are fitted with heavy gun-metal bushes, each cast in four pieces, rendered easily adjustable by two wedge-bolts. The crank-shaft is 10 inches in diameter at the inside journals and $7\frac{1}{2}$ inches in diameter at the outside journals; it is constructed on the "built" principle, and is fitted with two sets of double web-cranks placed at right angles to each other. The heavy fly-wheel, 16 feet in diameter, is built in eight segments bolted together; the rim has fifteen grooves suitable for ropes $5\frac{1}{4}$ inches in circumference. The valve-gear is of the usual slide-valve pattern for all the cylinders except the high-pressure one, which is fitted with Proell's automatic expansion-gear and governor. The exhaust from both ends of the cylinder is controlled by a single piston-valve worked by an eccentric and rod off the crank-shaft. The feed-pump is worked off the low-pressure piston-rod cross-head.

The exhaust from the low-pressure cylinder or cylinders of a compound engine in which there are only two successive expansions (or from the last cylinder or cylinders, where there are three or four successive expansions) may be either discharged into the atmosphere (in which case the engine is said to be "compound non-condensing") or conveyed to a condenser, in which case the entire system is said to be "compound condensing." Figure 1 (*pl.* 88) shows a tandem-compound condensing engine, both pistons acting on the same rod, and there being no receiver and but one crank.

The Corliss Engine has the original cock used to effect steam distribution developed into an oscillating plug, and the hand-power or simple cords employed to open and close it have been replaced by a beautiful automatic system, by which the governor permits a weight or an air-spring suddenly to close the valve when the time for cut-off (as determined by the governor itself) has arrived in each stroke. The use of four valves reduces to a minimum the waste clearance-space between the valves and the counterbore. The valves are given partial rotation by rods from a wrist-plate oscillated by an eccentric and giving sudden opening and prompt closing, while practically holding the valve still between opening and closing times. When it is time to cut off, the admission-valve is sharply detached from the driving mechanism. The detaching mechanism is directly connected with the governor, which has not to do the actual work of valve-moving. When either admission-valve is detached from the driving mechanism, it is closed by a spring, a weight, or a vacuum-pot. The oscillations of the governor are controlled by a dash-pot.

Tandem-compound Corliss Engine.—Figure 4 (*pl. 90*) is a good type of the Corliss engine arranged as a "tandem-compound"—that is, with the high- and low-pressure cylinders in the same axial line. In the example given, instead of the admission- and the exhaust-valves of each cylinder being worked from a common "wrist-plate" or disc, as is usual in the Corliss construction, there is in each cylinder one crank-disc to work the two admission-valves and one to work the two exhaust-valves. The two admission-valve discs are connected by a "parallel-rod," as are the two exhaust-valve discs. Each of the four admission-valve cranks is in communication with the regulating device, and also with the vertical rods extending from the dash-pot pistons and with its admission-valve wrist-plate, so that when the governor and its attached regulator-rods disengage the valve-cranks from the control of the wrist-plate rods, the valve is suddenly closed by the action of the dash-pot rod. The wrist-plates of the high-pressure cylinder (the one nearest the crank) are actuated by eccentric-rods from eccentrics on the main shaft, and in turn, by the parallel-rods shown, give motion to the wrist-plates on the low-pressure cylinder.

A lengthwise central vertical section of a horizontal Corliss engine is shown in Figure 1. Both admission-valves are closed, as is also the left-hand exhaust-valve, the right-hand exhaust-valve being open. Figure 2 shows the "tangent crab-claw" which hangs to the shaded piece shown in the cut, and which is attached to the valve-crank until the action of the governor depresses the entire claw- or thumb-and-finger-like member and allows the vacuum dash-pot piston, which has been drawn up by the crab-claw as the latter opened the admission-valve, to fall suddenly, thus closing the valve and cutting off steam quickly and sharply. The vacuum dash-pot is shown, with a part of its rod, in Figure 3.

The Centennial Exhibition Corliss Engines were such a marked departure from the usual type of construction of their builders, and by reason of their position were so prominent and familiar, that we have selected them for our *Frontispiece.*

These engines have a double-acting vertical beam, constructed upon the Corliss pattern. The frame is A-shaped, the beam-centre being at the vertex, with the cylinders and main shaft at the base angles; the various parts of the frame are in the hollow or box form, and the corners are flattened, producing a section almost octagonal. The cylinders are 40 inches in diameter, 10 feet stroke, and are rated at fifteen hundred horse-power collectively, with a capacity up to twenty-five hundred, the lesser power calling for about twenty-seven and a half pounds mean effective pressure per square inch. The single shaft to which they are connected carried at the Centennial Exhibition a gear-wheel 30 feet in diameter, 24 inches face, having two hundred and sixteen teeth, cut with a pitch of 5.183 inches. It has been stated that this is the largest cut iron gear ever made; it weighs fifty-six tons, and, at thirty-six turns per minute, its periphery travels at the rate of about thirty-eight miles per hour. The crank-shaft carrying this wheel is 19 inches in diameter and 12 feet long. The cranks

are of iron gun-metal, and weigh three tons each. The beams are 9 feet wide in the centre, 27 feet long, and each weighs about eleven tons. The connecting-rods, 25 feet long, are manufactured out of "scrap" iron, requiring in their construction ten thousand worn horse-shoes. The piston-rods are steel, $6\frac{1}{4}$ inches in diameter, with a speed of 720 feet per minute. The gearing by which motion was imparted to the shafting at the Exhibition was in covered ways under the floor. The great gear-wheel drove a pinion 10 feet in diameter, and parallel to its axis was a line of shafting diminishing from 9 to 8, 7, and 6 inches, the pinion gear weighing seventeen thousand pounds.

Diameter of cylinders, $3\frac{1}{3}$ feet; stroke, 10 feet; diameter of piston-rod (steel), $6\frac{1}{4}$ inches; speed, thirty-six revolutions per minute, corresponding to a piston-speed of 720 feet per minute; length of beams, 27 feet; depth of beams at centres, 9 feet; weight of each beam, eleven tons; length of fly-wheel shaft, 12 feet; diameter of fly-wheel shaft, 1 foot 7 inches; diameter of fly-wheel shaft in bearings, $1\frac{1}{2}$ feet; length of fly-wheel shaft in bearings, $2\frac{1}{4}$ feet; diameter of fly-wheel, 30 feet; width of fly-wheel across the face, 2 feet; number of teeth on fly-wheel, two hundred and sixteen; and weight of fly-wheel, fifty-six tons.

The main line of underground shafting was 252 feet long, running north and south. The first line of shafting, by means of four trios of mitre-bevels, transmitted power to eight 6-inch shafts at right angles, leading in different directions to walled pits under heavy standard frames which carried the driven pulleys on the ends of the shafting overhead. Each of the lines of shafting was capable of transmitting a power of one hundred and eighty horses at its normal speed, and was 658 feet long, reaching from the transept to the east and west ends of the building. The larger portion of these lines ran at the rate of one hundred and twenty revolutions per minute, but the one specially devoted to wood-working machinery made as many as two hundred and forty per minute. The total weight of the main gearing, shafting, mitre-gearing, and pulleys to which these engines were attached was 365,855 pounds; the weight of the engines, underground shafting, and boilers was 1,552,180 pounds.

The boiler-house connected with these engines was located 36 feet from Machinery Hall, and contained twenty upright boilers, each having the nominal power of seventy horses. The main steam-pipe, which was located under the floor, was of wrought iron, 320 feet long and 18 inches in diameter. These unparalleled engines were intended to operate a length of shafting estimated (main and subsidiary lines together) at 10,400 feet, and to answer the purpose of exhibition required by the larger portion of machines occupying a floor-space of about thirteen acres, of which machines more than eight thousand were in position on the opening day of the Exhibition.

The Wheelock Engine, as originally constructed (*pl.* 92, *fig.* 2), has but two ports, one at each end to each cylinder. Upon each of the valve-seats corresponding to these ports there is an oscillating valve which

admits steam at one fixed point and exhausts it at another. Back of or below each of these main valves is another oscillating valve, which causes cut-off by a detent motion regulated by the governor: the lighter the load, the earlier the cut-off. There is about this an elegant simplicity of design which leaves but little to be demanded.

The Greene Engine (*pl.* 91, *fig.* 1) has four flat valves. Those for the exhaust have their own eccentric-rods; those for admission have each a sliding bar which has motion parallel to the centre line of the cylinder and coincident with that of the piston. This bar has two tappets adjustable vertically, so as to engage rock-shaft arms on the ends of rock-shafts attached to the valve-links inside the steam-chest. Springs hold these tappets to their work and in contact with a "gauge-bar," which is adjusted to various heights by the action of the governor.

The "Buckeye" Engine is one of the most successful of those which have the cut-off automatically regulated by a centrifugal governor placed on the main shaft and controlling the position of the eccentric. There are three sub-types of construction, the latest of which is shown in Figure 3. Figure 2 is a horizontal section through the valves and cylinder corresponding to any one of the three sub-types, and Figure 16 (*pl.* 83) illustrates the governor employed in all. The live steam enters at *A* (*pl.* 91. *fig.* 2), whence it passes through passages (*a*, *a'*) and the open pistons *d*, *d* into the interior of the box slide-valve *B*, *B*, as shown by the arrows. From this box-valve it is admitted to the cylinder through ports (*b*, *b*) in its face as these ports are alternately brought to coincide with the cylinder ports. The cut-off valve, which consists of two light plates (*C*, *C*) connected by rods (*C'*), works on seats inside of the main valve, as shown, and alternately covers the ports leading to the cylinder. The cut-off valve-stem *g* works through the hollow stem *G* of the main valve. The exhaust takes place at the end of the valve (as shown by arrows on the right) into the valve-chest; thence into the exhaust-pipe *F* below. In the valve-seats (at *c*, *c*) are shallow recesses equal in area to the cylinder-ports, and called "relief chambers," their use being necessary at certain positions of the valve to counteract the excess of pressure tending to force the valve to its seat. In this engine the steam is within, instead of around, the slide-valve, as in most slide-valve engines, and the tendency of the steam in the ports *b*, *b* and in the cylinder is to force the valve from its seat, this being counteracted by the pressure of the entering steam in proportion to the area of the pistons or equilibrium rings *Dd*, *Dd*, which are proportioned to hold the valve to its seat at the moment of admission (see the left-hand end of the valve in *fig.* 2), when the tendency to leave the seat is greatest. At other times this pressure would be too great, hence live steam is admitted to the relief chambers *c*, *c* through the holes *f*, *f* in the valve-face just after it is exhausted from the cylinders (as shown at the right-hand ends of the valve in Figure 3), and in turn is thence exhausted, as shown at the left, just after the exhaust closure.

In the governor shown in Figure 16 (*pl.* 83) two levers (*a*, *a*) are pivoted to the arms of the containing case at one of their ends (as at *b*), while the movable ends are connected by links (*B*, *B*) to ears or flanges on the sleeve of the loose eccentric *C*, so that their outward movement in obedience to centrifugal force (as indicated by dotted lines) advances the eccentric in the direction of revolution. Springs (*F*, *F*) oppose the centrifugal tendency, the tension being adjusted by a screw at *c*.

Straight-line Engine.—The two special features in the frame of the "straight-line" engine are (1) its support on three self-adjusting points to free it from torsion, and (2) diverging straight arms in the frame, connecting the cylinder and the main bearings, as shown in Figure 4 (*pl.* 92). All boundary-lines are straight, ending in curves; all cross-sections of stationary parts rectangular, with rounded corners; and all moving arms and levers double convex, wide and thin, with the longest axis in the direction of the greatest strain. The frame is cast in one piece with the cylinder, steam-chest, cylinder-jacket, and brackets for rock-shaft and other parts. The valve controls the steam-distribution very much like a common D-valve, but has a variable travel controlled by the governor. As will be seen in Figure 6, the valve is a thin rectangular plate having through it five openings, working within an opening formed by the valve-seat and a pressure-plate and two distance-pieces. By recesses in the pressure-plate and the small openings through the valve there are opened double ports for the steam-admission and exhaust. A vertical section through cylinder and valve is shown in Figure 7. The piston-rod is made fast in the cross-head and the cross-head pin (or wrist-pin) is made fast to the connecting-rod, turning in two bearings in the cross-head. The eccentric is cast upon a swinging plate, which is pivoted to the boss of the fly-wheel. It is shifted by the governor, and change of its position changes its eccentricity or throw, the travel of the valve, and the point of cut-off. The crank-shaft and wheels, shown in vertical section in Figure 3, are very original. The crank-pin is oiled while the engine is in motion by means of an eccentric chamber on the outside of one of the balance-wheels and of holes drilled through the crank-pin. The waste oil from the inner end of one of the main bearings also finds its way to the crank-pin. The waste oil thrown from the cranks is caught in a recess in the inner surface of each wheel-rim. The main journal-boxes are split eccentric sleeves lined with Babbitt metal. The governor, shown in Figure 5, is a single ball linked to the eccentric and a spring, and so located and weighted as to counterbalance the eccentric. Increase of engine-speed moves the eccentric nearer the shaft, thus shortening both its throw and the valve-travel.

The Porter-Allen Engine (*fig.* 1), which claims to be the first and most perfect type of the high-speed steam-engine, is distinguished for originality of design and for its special adaptation to high-speed running, for attaining which every detail of construction and every movement are made satisfactorily subservient. The central feature of the valve-motion is a link actu-

ated by a single eccentric by which separate and independent movements are given to the steam-admission and exhaust-valves. The eccentric is part of the main shaft and has its centre coincident with the crank itself, so that both arrive at their dead points simultaneously.

The valves are all flat frictionless slides, working under plates which protect them from steam-pressure and permit at once four lines of opening, each the whole length of the port. Two valves for steam admission and two for exhaust are provided, each with the shortest practicable steam-way and least waste room. A highly sensitive and unique governor controls the point of cut-off by moving the block in the link. The movement of the exhaust-valves is constant. Mr. Allen invented the valve-gear, and in 1863 Mr. Porter designed the governor, and also the bed, from which all similar beds have been modelled.

Ideal Engine.—The "ideal" single-cylinder double-acting engine (*pl.* 92, *fig.* 8) is characterized by the valve (a hollow double piston, having steam on each end and on all sides) being driven by direct connection from a "shaft-governor" bolted to the fly-wheel and provided with a dash-pot; by the crank playing in a case containing a considerable quantity of oil, in which the crank discs dip, and which is so thrown by the crank-motion that it lubricates slides, cross-head pin, piston-rod, and all other parts requiring lubrication; by "pop-out cups," which burst if a dangerous quantity of water gets in the cylinder; by the cylindrical guides bored at the same time as the cylinder; by a very heavy frame and bed-plate; and by an "overhung" cylinder of the Porter type (known in England as the "Tangye"). The governor gives an open port at the beginning of stroke, and cuts off from zero to three-fourths stroke. There are no oil-cups on this engine, the system of lubrication providing for continuous circulation of oil through all bearings. About once a week the oil is drawn out of the case, filtered, and used over again.

The Westinghouse Engine has among its essential features—many of which are peculiar to it—single-acting inverted cylinders, having no piston-rods, but the piston driving the crank-shaft through a connecting-rod pivoted to the piston-head. The valves are cylindrical pistons. The crank case constitutes a receptacle for oil, in which the crank dashes at each revolution, thereby effecting lubrication of the crank-pin, man-bearing, and wrist-pin. This type exists in three varieties, of which the most recent and important is the compound engine shown in longitudinal vertical section in Figure 6 (*pl.* 93), a perspective being given in Figure 5. The functions of the working portions may be readily studied in Figures 1 to 4; Figure 1 showing the position of the valve and piston at the moment when the steam is being admitted into the high-pressure cylinder; Figure 2, when the steam in the high-pressure cylinder has been cut off; Figure 3, when the high-pressure cylinder is exhausting and the low-pressure cylinder is getting the exhaust therefrom; and Figure 4, when the exhaust of the high-pressure cylinder (which is the supply for the low-pressure cylinder) has been cut off so

as to cause cushion or compression, this leaving the low-pressure cylinder to work on expansion alone until stroke-end. Steam is admitted at s and finally exhausted at E; the space C between the valve-heads forms a clearance volume which is constantly in communication with the high-pressure cylinder through the annular port P. Steam is admitted to and cut off from the high-pressure cylinder by the valve-edge a, a; this being the only function performed by that end of the valve. The valve does not cut off on the port P to the cylinder, but upon another port (M), communicating only with the steam-pipe. Since the valve never reaches the port P, the latter is always uncovered, and the clearance volume C is therefore always in communication with, and a part of, the high-pressure cylinder during both the upward and the downward stroke of the piston. This clearance space bears the same relative proportion to the high-pressure cylinder that the latter does to the low-pressure cylinder. The remaining functions of the valve motion are all performed by the short end of the valve, of which the inner edge b, b effects release and compression in the high-pressure cylinder coincidently with the admission and secondary expansion in the low-pressure cylinder; the outer edge c, c effecting the release and compression in the low-pressure cylinder.

Miscellaneous Reciprocating Engines.—The principal types of reciprocating engines having been illustrated and described, it now remains in this class only to give a few more examples of various types of construction, both ordinary and unusual. Figure 3 (*pl.* 94) represents a German engine of large, and Figure 1 one of small, capacity. In these the cylinder and guides and one of the fly-wheel pillow-blocks are fastened to an iron bed-plate, which is bolted to a stone foundation. In Figure 2, a medium engine, the pillow-block is passed in one piece with the iron bed-plate, no masonwork foundation being used. Figure 4 shows a double-cylinder twin engine. In Figure 4 (*pl.* 95) we have an inclined double-cylinder engine. Figure 3 shows an engine attached to the boiler, thus saving the expense and room of a separate frame. Figure 6 shows a curious type of engine (Sulzer's), in which the fly-wheel is not on the crank-shaft, but is driven by a pinion upon that shaft; of course at a slower rate of speed than that of the engine. Figure 5 shows a three-cylinder engine in which there are three single-acting cylinders, with their axes 120° apart, driving a common shaft. Such machines, having no dead-point, start easily, and are used for direct-driving high-speed machines, such as saws, dynamos, etc.

Figure 1 (*pl.* 96) shows a steam-engine and boiler contained in a railway-car for convenience in doing construction-work along the line of the road. Figures 3 and 4 show forms of German "locomobiles" or traction-engines. Figure 2 illustrates a German semi-portable engine, with locomotive fire-box.

Geared Engines are those in which the screw or other rotating part driven by the engine is given, by means of gear, greater rotation speed than the engine. They were in use for marine work long after engines were known which could have been run at even a greater speed than the

screw might have been run at had the latter been made large enough. The term is usually restricted to marine engines.

Hoisting Engines.—For hoisting purposes there are generally used small double-acting reciprocating engines, geared to a drum upon which a rope or chain is wound and unwound (*pl.* 95, *fig.* 2). These engines must be quickly reversible, and as such machines are most often used in exposed situations, they need be of extreme simplicity. Usually they are attached to, as in the Figure, or are in close connection with, a portable boiler.

Sector Cylinders are very rarely seen. The ordinary cylinder is replaced by a cylindrical sector in which a rectangular piston oscillates, as on a hinge, on a rock-shaft which drives the crank.

The Disc Engine (*fig.* 1) has, instead of a regular cylinder, a spherical zone having for its ends a pair of cones the apices of which coincide with the centre of the sphere. The piston is a flat circular disc, which fits the interior of the spherical zone around its edge, and has in it a radial slit which fits a partition fixed in the cylinder and shaped like the cylinder sector. The disc is fixed to a ball, from which projects (perpendicular to the plane of the disc) a rod which acts as a crank-pin, its end fitting into a hole in the end of the crank. The disc and partition divide the cylinder into four spaces, two of which enlarge as the others contract, steam being let into the two former, and discharged from the two latter, by ports near the partition.

The Tendency of Modern Steam-engine Practice is toward higher and higher piston speed and rotation speed, as well as higher pressure and earlier cut-off. This tendency is by reason of the fact that the more rapidly the steam is used, the less it is wasted by condensation from radiation; the higher the pressure, the earlier the cut-off, and the greater the amount of work done with a given weight of steam; and the higher the rotation speed, the less countershafting, pulleys, etc. are needed to drive the machinery, the greater part of which is high speed. Of course the cost of small engines is less than that of large ones to do the same work. We must not, however, lose sight of the fact that in any steam-engine the fluid must enter the cylinder at as high a pressure as possible and leave it at as low a pressure, this reduction of pressure being by expansion, not by condensation in the cylinder; and that there must be no waste of heat by conduction and radiation. Within certain limitations, the engine which expands steam at from one hundred to twenty pounds pressure is doing more work than that which expands it only at from one hundred to fifty pounds.

3. LOCOMOTIVES.

Introductory.—A locomotive, considered as a whole, may be defined as an "engine running on wheels," or it may be treated as a boiler supplying steam to an engine for driving a propelling mechanism. Ordinarily, the term "engine" is applied, not merely to the cylinders, valves, and valve-operating mechanism, but to the entire machine. The importance of the subject, and the difficulty of separating the engine, or motor proper, from the rest of the machine as an entirety, leads us to devote a separate heading to the subject of locomotives, although this heading forms a part of the matter relating to steam-engines.

Locomotives differ essentially in their running-gear from the locomobiles previously mentioned (p. 274). In modern forms of construction the main portion of this running-gear consists principally of "driving-wheels" which have either a smooth periphery (in which case they act by friction upon the surfaces they touch) or a toothed periphery (in which case they catch into a comparatively soft basis or gear into a rack). The carriage is generally a wheeled vehicle, though sometimes a sled (*pl.* 104, *fig.* 3), and the motive machine is always a steam-engine.

According to the nature of the roadway over which they are to run, locomotives are differently constructed, and are distinguished as railway-, street-, field-, and ice-locomotives. Street-, and particularly field-, locomotives are called "traction engines," and where the arrangement for drawing attached loads is omitted, and the load consists of persons sitting on the locomotive itself, there are applied to it the terms (formerly in general use for the locomotive) steam-carriage, steam-omnibus, and steam-sled.

The locomotive, long in the minds of inventors an ideal wagon moving without driver and horses, has only recently been practically realized, and even yet, except for railroads, for whose use it has been crowned with astonishing success, there has been invented no locomotive likely to survive that entirely replaces the tractive power of horses or other animals. The real history of the locomotive begins with the period when iron railroads were first used. These were a development of the wooden tramways originating in the sixteenth century in Germany for mining, and consisting of flat wrought-iron straps spiked on wooden rails, these rails being replaced in England, about 1700, by low cast-iron rails, and these again, in 1820, by high rails of wrought iron or steel, or of both combined in one rail. (See Vol. V., p. 171.)

The invention of the locomotive is associated with that of the so-called "high-pressure" steam-engine—that is, of a steam-engine which can dispense with the condenser and can be made comparatively small, being for both reasons especially adapted as a motor for a vehicle. Oliver Evans, the inventor of the high-pressure steam-engine, was also the inventor of the locomotive. His first locomotive, the "Oruktor Amphibolos," was constructed in 1801, and in 1803 ran through the streets of Philadelphia. (See Vol. V., p. 172.)

The development and perfection of this invention, however, which should really be classed with street-locomotives, did not take place in America. It was perfected in England, where, independent of Evans, Trevithick and Vivian in 1802 took out a patent for the application of a high-pressure steam-engine to a wagon, and in 1804 produced the first practical railroad locomotive. This first English locomotive was of a crude type, and was soon succeeded by a number of scarcely less imperfect constructions by other inventors. They were mostly used for the comparatively slow transport of pig-iron, coal, and other heavy materials. Their running-gear consisted in part of a spur cog-wheel catching into a toothed central rail, or, instead of the wheel, they had a stake-like apparatus pressing against the ground. They were provided with complicated vertical beam-engines. In 1815–1820, however, George Stephenson brought out a form of construction which, perfected by his son Robert and greatly improved by other inventors, has since 1828 been practically the model of existing locomotives. By this invention Robert Stephenson gained nearly the same rank among his co-workers in this line that Watt occupies among the inventors of the steam-engine. (See Vol. V., p. 171, *et seq.*)

The successful application of the use of the locomotive was based on the fact that the friction or adhesion of a smooth wheel upon a smooth rail sufficed for propulsion, provided the road was nearly level; and a satisfactory result can be attained only by complying with these conditions and by arranging the engine horizontally and using a multitubular boiler, which, having more heating surface, is capable of producing a great quantity of steam in a limited space. Another step was the introduction of the so-called "Stephenson's link-motion," which allows of a quick reversal and a great variation in the degree of expansion. This apparatus, as improved by Allen, is shown in Figure 4 (*pl.* 97). Another important feature was in substituting for the bellows, or similar contrivance originally used for stirring the fire, the exhaust-nozzle and the blast-pipe.

General Arrangement.—Since the time of Robert Stephenson and his co-workers, the structure of the European locomotive has essentially become like that shown in longitudinal section in Figure 1, and in perspective, though on a reduced scale, in Figure 2 (*pl.* 98). The carriage consists of two plate-iron frames, parallel with the track, joined by the buffer-beam *p* and stiffened in several places by cross and diagonal struts. They enclose and are supported by the axle-boxes (*pl.* 97, *fig.* 2; *pl.* 98, *fig.* 7), in which rest the journals of the driving- and running-wheels *l*. These wheels differ from ordinary wagon-wheels in being fixedly connected to their axles, so that the axles rotate with them. Further, their peripheries are flanged on the inside (*pl.* 97, *figs.* 2, 3), and of late years have been slightly tapered conically toward the outside, although this practice is going out of use.

The frame does not rest directly upon the axle-boxes, but is supported on the ends of springs suspended from the boxes by means of a rod placed in their centre. The axle-boxes are movable vertically in the jaws hold-

ing them, but not horizontally; hence, with the locomotive upon a horizontal track, they shift in accurately vertical planes, so that, to allow for shocks caused by the unevenness of the track, the frame can move up and down, but its horizontal shifting upon the axles, crosswise of the track, is impossible. The motor, which is secured to the frame, is generally a twin steam-engine—that is, consists of two reciprocating engines of equal dimensions which act upon the driving-axle through their connecting-rods. Some recent locomotives have compound engines, the high-pressure cylinder upon one side and the low-pressure cylinder upon the other. It is necessary to have at least two engines, since the locomotive must be put in motion at every position of the piston and crank, including, of course, the two dead centres or stroke-ends of each engine. The two cylinders of this twin engine are secured on some engines outside and on others inside the frame, the outside connection being the exclusive American usage. Their pistons act, by means of piston-rods and connecting-rods, upon the cranks K (*pl.* 97, *fig.* 1), which, in the case of outside-cylinder engines, are placed outside on the driving-wheels, and with inside-cylinder engines are placed inside on the driving-axles, which are bent or otherwise "cranked" for this purpose. The cylinders are horizontal, or nearly so, to prevent undue compression and expansion of the bearing-spring m.

The driving-axle generally carries for each of the two engines two eccentric sheaves (*fig.* 4), of which it is usually said that one is for the forward and one for the backward motion of the locomotive, although really both are always rotating and acting. By means of eccentric-straps and eccentric-rods they act much like a crank mechanism upon the link-motion, which, according as it is raised or lowered by means of a bell-crank and lever (n; *fig.* 1), operates a rocker-arm fastened to the valve-stem, and thus regulates, through the distributing slide-valve, the admission, the degree of expansion, the exhaust, and the degree of compression. The present tendency appears to be in the direction of substituting for the eccentrics and their sheaves, as a means of working the valve-rods, what are known as "radial gears," which are driven from the cross-head, connecting-rod, or other reciprocating part, and not from any rotary piece. Of these the Joy gear appears to be the most promising and successful in England, while that of Brown of Winterthur, in many modifications, has been tried with satisfaction on the Continent. The movement has not gained much headway in America, although radial valve-gears are giving good satisfaction in marine work. Figure 5 shows, in section, the plan of two inside-connected cylinders (F), with piston (j), cross-head, steam-chest (G), steam-passages, three-port slide-valves, valve-rods (a), and guide-bars (l). (See under head of locomotive slide-valves, p. 202); also under general subject of slide-valves, p. 254).)

Upon the carriage and between the sides of the frame the steam boiler (*fig.* 1) is so secured as to allow it to expand lengthwise by heat without springing the frame. It has an inside fire-box (a) and flues (b), frequently over two hundred, placed between the fire-box a and the smoke-box c. There

is also an outside fire-box (*q*), enclosing the fire-box proper, a cylindrical shell (*f*) surrounding the flues, a dome (*c*), and a smokestack (*d*). The water is contained in the large cylindrical shell and in the space or "leg" between the inside and the outside fire-boxes, which are fastened together by a number of stay-bolts. The steam-pipe *g*, whose outlet can be opened and closed from the cab by a throttle-valve and rod (*f*), conducts the steam into the steam-chests, while the pipe *h* allows the exhaust steam to pass from the cylinders and through the comparatively small exhaust-nozzles into the stack. The effect of this exhaust is that the outer atmospheric pressure forces air into the ash-pan and through the grate *u*, driving the gases of combustion through the flues *b*. There is a safety-valve weighted with a spiral spring (*l*), and a feed-pipe (*w*) which conducts the feed-water from the tender through a flexible coupling (at *w*) between the locomotive and tender. This tender (*pl.* 101, *fig.* 5) is attached to the rear of the locomotive, and has a tank for water and bunkers for fuel. For throwing off obstructions there is further provided a pilot or catcher (*o*), which frequently carries vertical wire brooms to sweep the top surface of the rail-heads. The engineer's post on the footboard in all American engines is enclosed by a cab, and in most others is at least protected by a roof.

American locomotives differ from European locomotives in the following general arrangement: (1) in their frames, which are built up of bars of rectangular section instead of being made of plate iron; (2) in their cylinders, which are invariably outside the frames; (3) in the application of equalizing beams for distributing the weight; (4) in the absence of buffers, and in the use of a pilot or cow-catcher in front to throw obstructions from the tracks, which are less carefully guarded in America than in Europe; (5) in the use of a large headlight in front of the stack instead of two small ones over the buffers; (6) in the use of an enclosed and comparatively comfortable house-cab; and (7) in carrying a large bell. American engines use the dome almost universally; and those which burn wood have a large flaring stack which is unfamiliar to European engineers and travellers. The subjects of frames and outside-connected engines receive separate treatment in the following pages (pp. 287, 288), where they are considered especially with reference to their evolution in America; and equalizing beams are treated at length on page 291.

Adhesion and Weight.—The frictional adhesion of the treads of the driving-wheels to the rails constitutes the tractive power of locomotives. That this adhesion may be as great as possible it is necessary to load the driving-wheels with as great a portion of the locomotive's weight as it is safe to concentrate on such small areas of the rails. By a suitable arrangement of the springs, carrying the structure and resting on the axle-boxes of the wheels and of equalizing bars, nearly any desired fraction of the total weight can be thrown on the driving-axle; but this cannot be varied while running. The truck-axles—that is, those not rotated by the motor, but only sustaining the carriage—bear only a small proportion of the

weight. If the driving-axles or axle (*pl.* 97, *figs.* 2, 3, recognizable by their bearing large wheels) were loaded with the entire weight, and the running-axles in front and back had no load, the entire weight of the locomotive could be utilized in producing tractive adhesion, and the undesirable friction of the running-axles would be avoided. But in this case the locomotive would be suspended on the driving-axle in unstable equilibrium, and as it could turn horizontally on the rails it could easily be derailed. For this reason, and because with a too greatly concentrated load, which would endanger the substructure of the railroad, injure the ties and the rails, and destroy the fish-plates or other joints, the above-mentioned most favorable application of the weight for tractional adhesion is not made, and the form of construction in Figures 2 and 3 is employed, this being nearly identical with that in Robert Stephenson's first type of locomotives, which for fast trains require less tractive power than for heavy trains.

Axle-coupling.—The evils of concentrated loads are overcome by applying several driving-axles, so that the running-wheels are entirely or partially dispensed with by being converted into drivers. The additional driving-axles have their crank-pins so connected with those of the main driving-axles by parallel rods or "side rods" that one pair of cylinders rotates all the driving-axles. In Figures 3, 5, 6, 8, and 11 (*pl.* 98) there are two, in Figures 1, 2, 7, and 10 there are three, and in Figure 4 there are four driving-axles coupled together.

It might be asked, "Why not have all the axles coupled as drivers and have no running-axles?" The principal objection to such an arrangement is due to the curves of the track. A locomotive on a sharp curve, on which a chord equal to the distance between driving-wheel centres subtends a greater angle on the inside rail than on the outer, the rigid union of several driving-axles would cause a forcing apart of the rails and the consequent derailment of the machine. Hence the position of the wheels, as shown in Figures 2 and 3 (*pl.* 97), is retained for locomotives for fast trains, enormously large driving-wheels having been first used by Crampton. And hence also the use of coupled driving-axles for locomotives for freight trains, which run more slowly, but exert more tractive power.

Mountain railroads, which naturally have sharp curves, require especially powerful locomotives to overcome their up-grades. The utilization of the entire weight for tractive adhesion here seems eminently desirable, because the dead load has to be raised to the top of the mountain. Special efforts, therefore, have been made to use on these roads locomotives with coupled wheels, and to overcome the difficulties arising from the curves. A further advantage of coupled wheels is, that as on the down grade the locomotive must aid in checking the train, which would otherwise acquire too great speed by its weight, the more coupled axles there are where the track is imperfect the more effectively the steam is employed to reverse the engine. (The arrangement of American locomotive-wheels receives special treatment on page 289, and the evolution of the American driving-wheel is detailed on page 290.)

Trucks.—The disadvantages of curves was first sought to be overcome by the use of trucks (with two or four wheels), upon which rested the front, and sometimes the back, part of the boiler, in such a manner, however, as to enable the truck to turn and accommodate itself to the curves. For this purpose the truck is connected with the locomotive by a pin or bolt, placed as in Figure 8 (*pl.* 98; Nowotny's system), or over the centre of the truck or outside of it further to the rear, as in Figure 10 (Norris's system), in which the bolt does not serve as both fulcrum and centre of motion, but acts merely as a pivot, the fulcrum being a circular rail placed on the truck. If, as in the Norris system, the truck has but one axle, it is called a "Bissel truck;" and if it has two, a "Baessen truck," after their respective inventors. (American trucks are considered on page 290; the Bissel truck is made a special topic on the same page.)

Engerth's Locomotive.—More completely to utilize the dead load of the locomotive as well as of the tender (*pl.* 97, *fig.* 3; *pl.* 98, *fig.* 5)—which, being as unprofitable as a heavy unpaid-for freight-car, but which nevertheless has to be transported—not only all the locomotive-axles, but also those of the tender, may be coupled together, thus converting all into driving-axles. An example of this system is Engerth's Semmering-Railway locomotive, which in external appearance resembles that shown in Figure 4 (*pl.* 98), with the difference that it has three coupled locomotive-axles and two coupled tender-axles. By the peculiar construction of the tender, on which the back portion of the boiler rests, and to which it is secured by bolts, one of its driving-axles is brought close to the rear locomotive-axle in such a manner that the tender-axle is driven by a cog-wheel fastened to it, a second gear-wheel being fastened on an intermediary axle, and a third fastened on the locomotive-axle. The first tender-axle transmits the power by means of coupling-rods to the others. This mechanism has been replaced by an intermediary crank-shaft and coupling-rods.

Tender-locomotives.—To avoid this difficult connection, which is subject to wear and tear, the tender has been entirely combined with the locomotive—that is, the water-reservoir and coal-bunker have been placed on the locomotive. The term "tender-locomotives" is applied to these constructions, one of which, shown in Figure 10, can readily be recognized by the water-boxes placed over the frames. They may, however, be placed in the frames themselves or be arranged on the boiler like a saddle (*pl.* 103, *fig.* 1.)

Fairlie's Duplex Locomotive.—Very heavy trains are moved by two locomotives. If engines with coupled axles and separate tenders are used for the purpose, the tractive power, while it becomes exceedingly large, is very expensive, especially on account of two crews being required. To avoid this disadvantage, Fairlie has inseparably connected two tendered-engines, so that they can be handled like one and by one crew. The two boilers of this duplex locomotive consist of a single piece, their fire-boxes being in the centre and the smoke-stacks, with the four cylinders of the

two sets of twin engines, being on the outer ends. However, each of these motors is fastened to a truck provided with three axles, to which the term "motor-truck" is applied in contradistinction to trucks (*pl.* 98, *figs.* 8, 10), which have only running-axles. The two motor-trucks accommodate themselves to the curves independently of each other, while the long rigid boiler rests on them without preventing their turning, so that it is possible to round sharp curves without danger.

Meyer's Duplex Locomotive.—Previously to Fairlie's locomotive, Meyer constructed a duplex locomotive, in which the four cylinders were in the centre and the trucks were connected by special rods instead of by the boiler. Both these tender-engines appeared in 1851 among the competing engines for the Semmering Railway, the system now called Fairlie's being represented by Lausmann's engine "Seraing," and Meyer's by Günther's "Wiener Neustadt."

A future of great promise was prophesied by many for Meyer's and for Fairlie's systems. As regards the utilization of the entire weight in tractive adhesion, this prophecy would have been justified, but in many cases, as on the Semmering and Brenner railroads, tender-engines are not considered suitable, since their adhesion-weight decreases as the water and fuel are consumed, which would make a considerable difference where water- and fuel-stations were far apart. Throwing the dead weight of the tender on the driving-axles has for this reason been abandoned on the Semmering Railway, locomotives without trucks, but with four coupled driving-axles and an ordinary tender, being now employed (*fig.* 4). Moreover, it does not seem advisable to make the tractive power entirely dependent on the adhesion resulting from the weight. Under all circumstances the tires and rails suffer exceedingly from the resulting tangential force, and there are needed considerably higher and more expensive rails and a more solid and costly substructure; so that the comparison made of the contest between the locomotive and the road-vehicle structure, with that between the projectiles and armor-plates, seems very apt. If no axle of the locomotive were loaded more heavily than any one on the heaviest freight-car, the road and its appurtenances would not need to be so excessively solid as is now required solely on account of the heavy locomotives.

Disturbing Motions.—In consequence of the weights of the pistons, piston-rods, connecting-rods, coupling-rods, etc. being unceasingly thrown backward and forward in rapid alternation, the main and side rods having also a vertical motion, the centre of gravity of the locomotive constantly changes its position, instead of moving, as would be desirable for steady working, only in the direction of propulsion of the entire machine. In consequence also of the varying pressures against the frame, resulting from the use of a crank, the springs carrying the entire structure are constantly subjected to varying stresses, those upon the one side sometimes being strained more than those upon the other side, and those in front more or less than those behind. From these mechanical causes originate the peculiar short and quick oscillations and swinging motions,

which are divided into jerking, hammering, and "wee-wahing," generally called "disturbing motions."

Balancing.—In moving backward and forward the heavy constituent parts by themselves produce motions as if the locomotive were drawn to and fro upon the track (short-and-quick motion), and as if it run waggling in horizontal waving lines ("wee-wahing," reeling). The varying pressures on the springs impart to the locomotive vertical undulations, swinging motion (overbalancing or galloping), and rocking as if it were a cradle. The first two of these motions may be in part compensated by balancing-weights, which, like the counter-weight for the heavy cranks, are placed on the driving-wheels. The rest may be partially overcome by proper construction. But other circumstances make these compensations unsuitable. It would, therefore, be of advantage to use a construction which contains as few reciprocating masses as possible; or, still better, a construction with no reciprocating parts and working without a crank.

In this respect, such an engine, for example, as is represented in Figure 9 (*pl.* 98), with oscillating cylinders in which the pistons move toward and from each other, might solve the problem. Still more suitable, however, would be an engine with rotating piston or follower (a so-called "rotary engine") fastened directly on the driving-axle, which would use a single cylinder, or at least would not require two in order to overcome the dead points. But on account of the difficulty of solidly fixing an oscillating engine, and the exceedingly wasteful steam-consumption of the rotary engine, the ordinary reciprocating horizontal engine is still retained.

The endeavor is made to effect the compensation of the disturbing motions above mentioned by at least a partial application of the required counter-weights and by equalizing beams or double lever-like parts, which uniformly distribute the weights and pressures. In Figure 5, for instance, an equalizing lever is placed in a notch in the frame above the coupling-rod, between the coupled driving-wheels, for the reception of the one-sided spring pressures of these wheels, while Figure 2 (*pl.* 97) and Figure 6 (*pl.* 98) show the counter-weights fastened in the driving-wheels.

Weight and Tractive Power.—The locomotives built by A. Petzholdt weigh up to 100,000 kilogrammes (110 tons), and are constructed with an adhesion-weight (pressure against the tracks) of from 25,000 to 30,000 kilogrammes ($27\frac{1}{2}$ to 33 tons) if intended for passenger trains, and with an adhesion-weight of from 30,000 to 80,000 kilogrammes (33 to 88 tons) if intended for freight trains. They exert on the peripheries of their driving-wheels a tractive power of, respectively, 2500 and 6000 kilogrammes ($2\frac{3}{4}$ and $6\frac{1}{2}$ tons), and have an effective capacity of, respectively, six hundred and four hundred horse-power, that of a locomotive for passenger trains being, therefore, greater than that of one for freight trains, which is due to the greater speed of the first. Formerly, two hundred horse-power was considered an average of effective capacity.

Substitutes for Adhesion-weight: Fell's System.—The expedient of

using magnetism instead of weight-adhesion has frequently been tried, but without success. The use of a sand-box, as shown in Figure 11 (*pl.* 98), where it is in the shape of a cylinder close over the frame behind the smoke-box, for sanding the rails to increase the coefficient of friction, amounts to little more than a palliative and serves only for occasional emergencies. Another of the many expedients tried is the use of a central rail with a locomotive constructed on Fell's system. Figures 1 and 2 (*pl.* 104) show such a locomotive and track. Four horizontal wheels (two on each side) are pressed against a high central rail by a spring mechanism (represented half in section in the ground-plan in Figure 2). These are moved by a twin-engine so that the balanced compressing strains do not depress nor displace the central rail. There are two coupled driving-wheels, and the engine is a tender-locomotive with water-tanks on the side of the boiler over the frame. This locomotive was constructed for a temporary road over Mont Cenis before that mountain was tunnelled, but it has many practical defects. On the railroads ascending the Riga and the Kahlenbergs, near Vienna, a return was made to the historical initial point—namely, a central rack-toothed rail. Locomotives with corresponding spur-gear wheels were used, this being necessary on account of the enormous grades. (See Vol. V., p. 233.)

The form and even the dimensions of the steam-engines used in locomotive construction have undergone but little change since Robert Stephenson's time. Two practically horizontal cylinders are placed either on the outside, as in Figures 3 to 6, 8, 10, and 11 (*pl.* 98), or on the inside, as in Figures 1 to 3 (*pl.* 97) and Figures 1, 2, and 7 (*pl.* 98). The pistons, moving alternately backward and forward therein, generally drive directly, by means of piston-rods and connecting-rods, a crank-shaft, which is the principal driving-axle, and on which in most cases is placed the eccentric acting on a link-motion (usually Stephenson's). In Figures 5, 8, and 11 (*pl.* 98) the eccentrics are outside, a construction by no means suitable.

Tanks.—A saddle-tank on the top of the boiler has the disadvantage of not holding very much, and as the water-supply diminishes, the weight upon the drivers diminishes also, so that at one time there may be upon them too much weight, and at another there may be too little weight. Three types of American locomotive tanks are shown in Figures 3 to 5 (*pl.* 100).

Tenders.—Figures 5 and 6 (*pl.* 101) show two tenders, the first of the ordinary American type, but the latter with the special provision that the water-tank can be filled without stopping the train. For this purpose a long water-trough is placed between the rails on a horizontal stretch of the track. In the interior of the water-tank of this tender (invented by Ramsbottom) is a pipe over an aperture in the bottom, and another which can be either pressed against this aperture or turned from it. This second pipe being dipped into the water-trough while the train is running, the water is scooped up and the tank filled by the momentum of the train and the inertia of the water.

Early American Locomotives.—The earliest Baldwin engine was the "Old Ironsides," built in 1832 (*pl.* 99, *fig.* 1), a four-cylinder engine of English type, and weighing in running order a little over five tons. The cylinders were 9½ by 18 inches, and were attached horizontally to the sides of the smoke-box, which was D-shaped and recessed to allow the centre lines of the cylinders to be in line with the centre of the crank. The valve-motion for each cylinder was a single loose eccentric placed on the axle between the crank and the hub of the wheel. On the inside of the eccentric was a half-circular slot, running halfway around; the stop, which was fastened to the axle at the arm of the crank, terminated in a pin which projected into the slot. The engine was reversed by changing the position of the eccentric on the axle by a lever worked from the foot-board. Subsequently, this form of valve-motion was changed to a circular fixed eccentric, with rock-shafts having arms above and below, and the eccentric straps had each a forked rod, with a hook or an upper and lower latch or pin, at their ends to engage with the upper or the lower arm of the rock-shaft. The cylinders exhausted against each other at first for the reason that the exhaust-pipes were not properly arranged, a defect that was afterward remedied by turning each exhaust-pipe upward into the chimney, substantially as is now done.

Boilers of early American locomotives were similar to the boiler of Stephenson's "Planet" (*fig.* 4)—that is, they had a semi-cylindrical top, flush, or nearly so, with the top of the barrel, and also had a square, or nearly square, horizontal section of the fire-box below the barrel. About 1837, Bury of England made the top of the furnace hemispherical, and the horizontal section below the waist was D-shaped, with the flat part in front. This form of boiler was very soon adopted in America (*fig.* 3). Coal (first used by the Baltimore and Ohio Railroad) required larger fire-boxes than wood, and the hemispherical top was succeeded by a semi-cylindrical type, the crown-sheets being stayed by crown-bars running either lengthwise or crosswise. These semi-cylindrical tops, which were at first flush with the tops of the barrels, were followed by the "wagon-top" (*pl.* 74, *figs.* 6, 7), the semi-cylindrical furnace-tops coming higher than the top of the barrel, giving more steam-room and allowing more tubes to be used, and also affording better facilities for construction, inspection, and repairs. Baldwin adhered to the dome until 1850. For the use of anthracite, which required longer boilers than bituminous coal, there was produced the Millholland type (*figs.* 1, 2), which had a fire-box top sloping down from the barrel, and whose crown-sheet was screw-stayed. This was first introduced on the Philadelphia and Reading road. The Belpaire fire-box (*pl.* 75, *figs.* 3, 4), having a flat top as high as the cylindrical part of the barrel, is used upon some American roads. The smoke-boxes were not "extended" until about 1859, and in that year also there was added the deflector, which had an adjustable piece at its lower edge. The telescopic or adjustable "petticoat pipe" was introduced about 1862.

The Spark-arrester is one of the most important minor accessories of the locomotive, by reason of its great influence in preventing destruction of property along the line. About the first device was a wire "bonnet" placed over the whole stack; this was followed by a conical "deflector" over the smoke-pipe proper. There have been so many various combinations of cones and wire netting that it would be impossible to mention them all here. One of the few departures from these, however, consists in the addition of a water-tank below the ordinary diagonal deflector, against which the sparks are driven and thrown down into the water, while the gases of combustion make a turn around the edge of the plate and go up the stack. Another type had a number of spirally-arranged screw-blades through which the current of gases had to pass, and the sparks, being thrown against the sides of these blades, were stopped in their upward course and made to fall back into the "front end." The extinguished sparks found in the tank at the end of a run show what has been prevented from going up the stack and out into the air. The fact that the material which is collected from the various spark-arresters is fairly combustible shows that there would be economy in their use. Figure 2 (*pl.* 100) shows a spark-arrester for bituminous coal, and Figure 1, one for wood.

Luttgens proposes an arrangement of dampei by which the effect of the exhaust might be diminished by admitting air to the base of the stack when desired.

Feed-water Heaters for locomotives have been repeatedly tried, but have not met with success or favor. One of the earliest, which was carried under the front end of the boiler, was about the same in general design as the ordinary horizontal multitubular heater for stationary boilers.

Grates.—Cast iron is the material of which nearly all locomotive grates are made in the United States, and this has been the case almost since the introduction of railroading here. Cleaning-grates are necessary for grades of bituminous coal, which have a tendency to "clink." Some of these grates have projecting side-lugs cast on each bar, the lugs of one bar projecting between those of the other, the cleaning being done by a slight upward-and-downward movement of each bar. In the finger-bar type the bars have a rocking motion upon axes lying across the fire-box, and the fingers are made to project into the fire (*pl.* 74, *figs.* 3, 4). There are also employed wide flat bars rocking upon journals at the sides, each whole bar acting as a wide finger. The water-tube grate, which consists of lengthwise tubes passing through thimbles from which they can be removed (*figs.* 1, 2), is very common for anthracite. A solid bar takes the place of every fourth tube. Water-grates were used in the Milholland boiler.

Brick Arch.—A brick arch supported upon water-tubes, which extend diagonally from below the tubes to a point nearly midway of the length of the crown-sheet, has been tried; also one carried by tubes extending diagonally from below the tubes to a line in the back of the fire-box just above the fire-door. The brick arch was first employed in 1854 upon the

Pennsylvania Railroad. Figures 5 and 6 (*pl.* 75) show one variety. The long combustion-chamber with a water-bridge was produced for the New Jersey Railroad and Transportation Company about 1861. In the following year the Chicago, Burlington, and Quincy Railroad tried a water-leg which projected diagonally upward from the front of the fire-box in face of the door; and about four years later this was followed by the much-discussed brick arch, having the same position and inclination. The diagonally-inclined water-leg was developed into the Buchanan water-leg (*figs.* 1, 2), which extended diagonally upward entirely across the fire-box, leaving only a hole for the passage of the gases of combustion.

Tubes.—With the substitution of coal for wood as fuel, iron tubes were used in the United States instead of copper and brass, and leaky tubes were at first common by reason of there being no steam-gauges in general use, the safety-valves being the only guides as to the pressure. Tubes were at first fastened by expanding them in by a tapered mandrel driven in, and then a wrought-iron thimble was driven in. The introduction of cast-iron thimbles instead of brass is due to Hudson, and they were first used upon the Erie Railway. Copper tube-ends brazed on, with a steel thimble, were found to give tight tubes, but a better way was soon adopted by putting the copper end outside the iron tube and by using the end of the tube itself as the thimble. In 1835, Baldwin patented the method of driving a copper ferule on the outside of the end of the tubes, instead of inside.

Outside-connected Engines.—Builders on the American side of the Atlantic early became convinced that inside-connected engines—that is, those having cranked axles—cost more to build and to keep in repair than those with outside cylinders, and required more skill in counterbalancing, while they were no steadier nor faster. The "Stockbridge" of 1842 (*pl.* 99, *fig.* 5) had outside cylinders, but a pair of trailing wheels behind the driving-axle considerably reduced the adhesion. In 1836, Campbell patented the use of two pairs of drivers connected by a side rod or parallel rod (*fig.* 2), and in 1844 this was adopted by Rogers and became known as the "American" type. The first Rogers's engine which had this arrangement is also claimed to have been the first to have an equalizing beam between the driving-wheel and the truck (*fig.* 6). Outside cylinders were first bolted to the smoke-box, which method was feasible because the cylinders were inclined downward. But with horizontal cylinders it was necessary to extend the smoke-box downward and to give it a base, generally of rectangular outline with a reinforcing piece around its front edges inside. Inside cylinders were fastened to the smoke-box and frames by means of two castings, which fitted the lower cylindrical side of the smoke-box and were bolted together in the middle. Later the smoke-box was given a rectangular downward projection, with a cast-iron bottom and a distance piece, and the cylinders were bolted to the sides of this projection and to the frames. This developed into a design which added a cast-iron bottom to the smoke-box. Next, the box was kept cylindrical and a heavy bed casting was bolted to its lower side, with pas-

sages cored in it for the steam- and exhaust-pipes, the cylinders being bolted to its sides. This was followed by the plan, now in general use (*pl.* 100, *fig.* 6), of making the saddles in halves bolted to the bottom of the cylindrical smoke-box, on the top and together in the centre, each casting being made in one piece, with the cylinder on that side. By 1865 horizontal cylinders were the rule. A good illustration of the cylinders of American locomotives is shown in Figure 7. These cylinders are reversible and interchangeable, and are made of the best close-grained iron as hard as can be worked.

Frames.—Early locomotive frames were of plates, with wood-filling between, and the journal-bearings were outside the wheels. Bury introduced the bar-frame, which is now exclusively used in the United States, and is one of the distinguishing characteristics of the American engine. At first the whole frame was forged in one piece, but afterward for convenience in repairing the front and back ends were made separate and then bolted together. Some narrow-gauge engines have the main frames in the usual position inside the wheels, but have a supplementary frame or offset bolted to this to carry the fire-box. The old style of wooden frames was abandoned by Baldwin in 1839, and no outside frame whatever employed, the machinery as well as the truck and the pedestals of the driving-axles being attached directly to the naked boiler.

In 1839, Baldwin invented a geared engine with an independent shaft or axle between the two truck-axles connected by cranks and coupling-rods with cranks outside the drivers. This shaft had a central cog-wheel engaging on each side with intermediate cog-wheels which in turn geared into wheels on each truck-axle, the intermediates having wide teeth, so that the truck could pivot while the main shaft remained parallel with the driving-axle. This type not proving a success commercially, he in 1842 invented for accomplishing the same purpose the six-wheel connected engine, with the four front drivers combined in a flexible truck, the rear box being rigid in the frames (usually behind the fire-box) and having inside bearings. The remaining wheels had inside journals running in boxes held by two wide and deep wrought-iron beams, one on each side, which were not connected. Their pedestals were bored out cylindrically, and into them were fitted the cylindrical boxes which Baldwin patented in 1835. A spherical pin running down from the frame bore in a socket in the beam midway between the two axles. Thus each side beam independently could turn horizontally or vertically under the spherical pin, and the cylindrical boxes could turn in the pedestals. This was followed by a flexible-beam engine with but four wheels connected to compete with the standard "American" eight-wheel type, with four wheels connected. Baldwin made the forward wheels of smaller diameter as leaders, but connected them with the front drivers in a flexible beam-truck.

Figure 8 shows the frame of the "American" type of locomotive; Figure 9, of the "Mogul" or ten-wheels' style; and Figure 10, that of

the "Consolidation" type. It will be seen how much these differ from the plate construction used in the engines built in other countries.

Arrangement of American Locomotive Wheels.—In 1833 the Norris locomotives had the drivers before the fire-box. All the engines built by Baldwin in 1834 had the driving-wheels back of the fire-box. The Norris and the Baldwin systems of placing single driving-axles, one behind and the other in front of the fire-box, were combined about 1835. Campbell used two pairs of driving-axles, one pair in front and the other behind. The Forney engine (*pl.* 102, *fig.* 2) has both driving-axles between the fire-box and the smoke-box, and the tender and part of the cab are carried partly by a four-wheeled truck and partly by the main frame of the engine, thus giving the driving-axles a part of the tractive weight without putting too much upon them. There is no leading truck in the Forney engine proper, but it is frequently built with a "pony" leader. The Hudson "double-ender" (*pl.* 103, *fig.* 1) was constructed for the purpose of enabling an engine to run "either way to" for short runs. It has a long wheel-base to give steadiness, yet sufficient flexibility to enable it to round short curves with ease and safety. There are two driving-axles between the furnace and smoke-box and a pony truck at each end. As this plan still brought the water-tank, with its varying weight, on top of the boiler, a development of this double-ender was a locomotive having at the rear end a four-wheeled truck which carried the tank, and also having a Bissell truck at the front end.

In 1836, Campbell patented the eight-wheeled engine, with four driving-wheels in connection with a four-wheeled truck in front. This, the first engine of the "American" eight-wheeled type, had no equalizing beam (*pl.* 99, *fig.* 2). The eight-wheeled connected engine (*fig.* 7) was introduced by Baldwin in 1846, the first one of these having inclined cylinders, as do many engines of the present day built by Porter, particularly those for narrow-gauge service. In 1846, Norris patented the ten-wheeled engine with six drivers connected. Ten-wheeled outside-connected engines with straight axles were first built by Rogers for the Savanilla Railroad, and the connecting-rod took hold of the outside journal of the main crank-pin.

The "Mogul" engine (*fig.* 8), having three pairs of driving-wheels coupled together and a two-wheeled truck, was made possible by the invention of the Bissell or "pony" truck, and practicable by A. F. Smith's addition of swing-links. The two-wheeled truck enables the wheels to be placed farther forward than where there are four wheels, and this of course puts a greater proportion of the weight upon the drivers than is put on the drivers of ten-wheeled engines. A further development of this Mogul type is the "Consolidation" (*pl.* 101, *fig.* 8), which has a pony truck and four pairs of driving-wheels coupled together, which system throws a still greater proportion of the weight upon the drivers.

Switching engines are generally built with four coupled wheels and

with both axles between the furnace and the smoke-box. These may have separate tenders or have a tank saddled on the top of the boiler. More powerful switching engines are made with six coupled wheels between the fire-box and the smoke-box, and some also have six wheels coupled, but with one of the axles behind the fire-box; but this throws rather too great a proportion of weight upon the front pair. It is best for many reasons to balance the weight of the cylinders and smoke-box by the weight of the fire-box.

The ten-wheel fast-passenger locomotive of the Maine Central Railroad, which is shown in Figure 1 (*pl.* 102), is one of ten similar ones in service on that road, and it is claimed that it is a better type of locomotive for fast-passenger traffic than the ordinary American type. This engine has cylinders 19 by 24 inches and drivers 68 inches in diameter; it has a rigid-wheel-base of 6¼ feet and a driving-wheel-base of 12 feet 2 inches. Of the total weight of 118,000 pounds, 94,000 pounds are on the drivers. This engine, in addition to its tender, will pull 2000 net tons at the rate of thirty miles an hour on a level, or 247 net tons on a grade of 150 feet per mile.

American Locomotive Trucks.—Early American engines had their truck-axles as near together as they could be placed, which would answer for engines with inclined cylinders, but was not necessary when the cylinders were put lower down and made horizontal. The most commonly-used engine truck in America is that designed by Rogers about 1850, the frame being rectangular, with pedestals bolted to it, and having a pair of bent equalizing levers on each side and the spring between the wheels, each spring having its convexity upward and bearing at its middle against the lower edge of the frame, while its ends draw from points about midway between the centre and the ends of the equalizing lever. About 1852 there was introduced a truck which had journal bearings inside and outside of the wheels, and springs to each journal, there being double springs and two equalizing bars on each side of the truck.

Bissell or Pony Truck.—In 1857, previous to which time all trucks were centre-bearing, Bissell patented the truck since known by his name. The first Bissell truck had four wheels (*pl.* 100, *figs.* 16, 17), its distinctive features being that the frame was extended backward, and the pin, instead of being in the centre of the truck, was behind the rear axle (C), so that the entire truck, instead of making a partial rotation around its centre, made a vibration about this point behind the rear axle; the weight of the engine being taken by a pair of V-shaped inclined planes where the old centre bearing had been. The object of this arrangement was to enable the engine better to adapt itself to the curves of the track. In 1858, Bissell introduced the single-axle or "pony" truck, with the same vibrating feature. In 1862, A. F. Smith substituted for the inclined ways of the Bissell truck a set of pendent links to allow the engine to have lateral motion, the engine resting upon a bolster swung from the truck. Hudson in 1864 brought out a variation of the Bissell-Smith truck, using a long radius-

bar pivoted at its front end to a pair of lugs attached to the centre-pin plate of the engine, the back end having some motion, but being confined by a guide. A very important invention was that of Hudson in 1864, in which an equalizing lever was placed between the two-wheeled truck and the front driving-wheels, so that these accommodated themselves to the vertical as well as to the lateral motion of the engine.

Driving-wheels.—In 1834, Baldwin patented the improvement of casting together the hub and the spokes of the drivers, the spokes terminating in separate flanges or segments of a rim having wooden felloes, outside of which came the tire. For altering wide-gauge to narrow-gauge drivers, where the change of gauge in the road is expected at the time that the engines are built, Rogers casts a circular projection on the inside of the wheel-centres. The tires are then set to conform to the wide gauge. When the time comes to change the gauge the tires are simply moved farther in to cover the projection, and the portions of the centres thus exposed on the outside of the wheel are turned off, which leaves the wheel seats in proper condition for the narrow gauge. A driving-wheel for an American locomotive is seen in Figure 15 (*pl.* 100). It is made of good strong, close-grained iron. The counterweights are generally cast in; the rim and arms are solid or cast hollow as desired. Both the rim and the counterweights are divided in several places to diminish the inherent strains due to cooling.

Equalizing Beams.—Between the wheels of early American locomotives there were used ordinary equalizing levers, their method of attachment and arrangement varying according to the design of the engine and the fancy of the builder. The main features of the leading system at present are elliptical leaf-springs, which have their convexity downward, and which are attached at their outer ends to links drawing on the bar of the frame, and drawing at their inner ends on a lever which also draws on the frame at its centre. By this means any excess of draft of the leading pair of drivers is partly thrown upon the springs of the following pair, and *vice versa.* For narrow-gauge engines Rogers uses a long lever extending from pedestal to pedestal, and having the two links drawing upon the two ends of the spring, which has its convexity upward and which thrusts against the lower edge of the frame. For "Consolidation" engines the spring over the central driving-axle bears at its centre upon that axle, and its ends draw on the inner ends of two levers, the other ends of which receive the pull of the inner ends of the springs of the first and third axles, while the outer ends of the springs of these last axles draw upon the top of the frame. Good examples of equalizing levers are seen in Figures 11 to 13, being respectively main, truck, and pony-truck levers. In 1834, Baldwin patented a method of throwing a part of the weight of the tender upon the driving-axles to increase the traction, and thus to make up for the tractive advantage that Norris had by having the drivers in front of the fire-box. Baldwin proposed to equalize the pressure between the two

driving-axles by connecting by a pipe two air-springs on each side. Eastwick and Harrison patented the equalizing beam.

Axles.—Baldwin produced the "half-crank" axle, whose outer cheek was omitted and whose "wrist" was fixed in a spoke of the wheel. This strengthened the axles and allowed the boiler to be lower down and larger in diameter, and also permitted the driving-axle to be back of the fire-box, while the connecting-rods passed by the side of the fire-box and took hold inside the wheel. This involved putting the cylinders outside the smoke-box. Among the last engines on which the half-crank axle was used were those for the Erie road in 1849. For some years after 1835, Baldwin built his engines with cylindrical pedestals for the driving- and tender-wheels. In 1852 the driving-boxes were made with a slot in the line of the vertical bearing of the journal, to distribute the wear more evenly. The straight driving-axle needs no illustration; the crank form, which answers for inside-cylinder engines, is shown in Figure 14 (*pl.* 100).

Locomotive Slide-valves.—Early locomotive valves were of the slide pattern (plain "D"), and "hook-gear." Some of the early engines had the eccentric outside the journals and wheels. It was not long before independent cut-off valves were devised. Rogers as early as 1843 gave much thought to the subject of working steam expansively. Many of the engines of 1848 had independent cut-off valves, such as are now again coming into use. In 1852, Baldwin produced a variable cut-off with a riding cut-off valve, which fitted almost tight to the main valve below and to the sides of the chest.

Baldwin introduced what is called the half-stroke cut-off, in which the chest was separated into an upper and a lower part by a plate on which rode a separate cut-off valve. About 1868 the Bristol roller-slide valve was introduced, the pressure of the slide being taken by anti-friction rollers, but it was abandoned after extensive trial.

About 1882 the Allen valve was introduced, both balanced and unbalanced; as now balanced by Richardson, it is doing good service. Its peculiarity consists in a supplementary port cored out in the valve itself, so as to admit steam into the steam-port both inside and outside the lip, thus requiring but one-half the valve-travel that is needed where steam is let in only at the outer edge of the lip.

Link-motion.—James first employed the link-motion in 1832, and the Stephensons used it at once in England, but it was not until 1849 that it was adopted in the United States, where its introduction was violently opposed. Rogers used the suspended link (*pl.* 101, *fig.* 1) in 1849, and in 1850 the shifting link, which had the lifting-shaft below the link (*fig.* 2); but the front axles of some ten-wheeled engines coming in the way of the rocking-shaft, he put the shaft above the link. As early as 1854 there was used by Rogers a combination of independent graduated cut-off valve with the link (*fig.* 3). For some ten-wheeled engines Hudson made curved eccentric-rods, so as to clear the axles. In 1886, Uhry & Luttgens applied a supplementary cam-motion to the link to give greater steam-

port opening and to retard the exhaust without affecting the compression. At first, counterweights were used for balancing the weight of the shifting-link, but afterward leaf-springs were used, then helical and volute.

Power-brakes.—The great and increasing weight and speed of railway trains have rendered necessary some means of bringing them rapidly to a standstill from a high rate of speed. This is usually accomplished by increasing the friction of the wheels throughout the train by pressing against the treads of the wheels "shoes" composed of iron and conforming closely to the periphery of the wheels (at the same time shutting off steam and in some cases reversing the engine). In this way the resistance to the train's ongoing is greatly augmented, and a portion of the train's momentum is absorbed in the production of heat at the contacting surfaces, and in the removal of portions of iron from the brakes and of iron or steel, as the case may be, from the wheel. The proper points at which to apply the brake-power to the wheels (supposing these to be the places at which the friction was created) would be at the sides of the tires, or upon the peripheries of the friction-drums, concentric with the wheels and either made in one therewith or fastened to the same axles. By this means there would be obviated the reduction of diameter of the wheel—an objectionable feature, in that maintenance of the original diameter is desirable and that the material rubbed off is expensive, also that when the tire gets worn down to a certain thickness either the whole wheel must be discarded (in the case of cast-iron wheels) or the old tire must be removed and a new one put on.

But the proper place of application of the brake-shoe is the rail itself. Absolute prevention of rotation of the wheel at once produces "skidding," which causes flat spots on the wheel-tread, makes the riding rough, and endangers the train. Any lessening of the peripheral speed of the wheels to a rate less than the lineal speed of the train upon the rail, also causes injurious action and wear of wheel or rail or both. But at present the crude method of brake-application to the wheel-treads is adopted, and the devices for effecting this are most prompt and effective.

Of the various agencies employed to produce the requisite pressure, four may be named: (1) mechanical means derived from the rotation of the axles themselves; (2) hydraulic pressure conveyed through pipes joined between each two cars and applied at the engine; (3) air-pressure similarly conveyed through pipes and put on at the engine; and (4) the so-called "vacuum" acting through a continuous pipe system and operated at the engine. Of all these, the hydraulic system seems to have failed of general or even wide adoption. The mechanical brake, applied when the engine is reversed or when, from any other cause, the bumpers of two cars approach each other with force, has its advocates and has met with success, but is not widely (if at all) employed for passenger-service. The "vacuum" system, in which there is produced in the pipes and on one side of a system of diaphragms connected with the brake-beams a vacuum made by a jet of steam escaping through a concentric pipe, is the

only one suitable for such service as that of the elevated railroads in New York and Brooklyn, where there is not sufficient time between stops to enable an air-brake to be pumped up. It permits of continuous application as long as the steam-jet is "on," and can be put on and off in rapid succession about as fast as the manipulating lever can be operated.

But the system which has practically the monopoly for passenger-service, and which is being extensively introduced in freight-service, is the air-brake, which is all the more efficient in that in its most recent adaptations it is automatic—that is, not only can it be applied by the engineer at will or by the trainmen at any point in the train-length, but it is also automatically applied in case the train parts or a break, disconnection, or leak occurs in the air-pipe system.

The Westinghouse Air-brake consists of the following essential parts: (1) the steam-engine and pump which compress the air, the steam-supply being regulated by the pump-governor; (2) the main reservoir, in which the compressed air is stored; (3) the engineer's brake-valve, which regulates the flow of air from the main reservoir into the brake-pipe for releasing the brakes, and from the brake-pipe to the atmosphere for applying the brakes; (4) the main brake-pipe, which leads from the main reservoir to the engineer's brake-valve and thence along the train, supplying the apparatus on each vehicle with air; (5) the auxiliary reservoir, which takes a supply of air from the main reservoir through the brake-pipe and stores it for use on its own vehicle; (6) the brake-cylinder, which has its piston-rod attached to the brake-levers in such a manner that, when the piston is forced out by air-pressure, the brakes are applied; (7) the triple valve, which connects the brake-pipe to the auxiliary reservoir and connects the latter to the brake-cylinder, and is operated by a sudden variation of pressure in the brake-pipe, so as (*a*) to admit air from the auxiliary reservoir to the brake-cylinder which applies the brakes, at the same time cutting off the communication from the brake-pipe to the auxiliary reservoir, or (*b*) to restore the supply from the brake-pipe to the auxiliary reservoir, at the same time letting the air in the brake-cylinder escape, which releases the brake; and (8) the couplings, which are attached to the flexible hose and connect the brake-pipe from one vehicle to another. These parts are all shown in the illustration (*pl.* 103, *fig.* 4), the arrangement being substantially as used on the train.

In each car there is a "conductor's valve," with a cord running the entire length of the car; and by pulling this cord any trainman can open the valve and let the air escape from the brake-pipe, thus applying the brake. (It is necessary, however, to hold this valve open until the train comes to a stop.) There are, as auxiliaries, a gauge for showing the pressure in the main reservoir and brake-pipe in the releasing position of the engineer's brake-valve, and the pressure in the brake-pipe alone in the running position of the same valve.

The air-pump is shown in detail in the Figure. The steam from the boiler enters the top cylinder between two pistons forming the main

valve, the upper of which is larger than the lower, so that the tendency of the pressure is to raise the valve unless held down by the pressure of a third piston, of still greater diameter, working in a cylinder directly above the main valve. The pressure upon this third and largest piston is regulated by a small slide-valve working in the central chamber on the top head, and receiving its motion from a rod (extending into the hollow piston) which has a knob at its lower end and a shoulder just below the top head. This valve-chamber in the top head is in constant communication with the steam-space between the two pistons of the main valve. While the steam acts on the third piston and holds the main valve down, steam is let in below the main piston, and as this piston approaches the upper head the reversing valve-rod and its valve are raised until the slide-valve exhausts the steam from the space above the third or reversing piston, when the main valve is raised by the steam-pressure on the greater area of its upper piston. This movement of the main valve admits steam to the upper end of the main cylinder. When the main valve is moved up to admit steam to the upper end of the cylinder, it opens an exhaust-port at the lower end, just below the lower steam-port, which is closed by the lower piston and the main valve. When the main piston is on its upward stroke the upper exhaust-port is similarly opened.

To put the brakes on with full force, the air in the main brake-pipe is allowed to escape, so that the greater pressure in the auxiliary reservoir forces the piston down on a graduating-stem and closes the feed opening past the piston. The descending piston moves with it the slide-valve and lets air flow directly from the auxiliary reservoir into the brake-cylinder, thus putting on the brakes.

The Engineer's Brake and Equalizing Discharge-valve, sectional cuts of which are shown in Figures 2, 3, (*pl.* 103), is a device designed especially to assist the engineer in operating train-brakes in a more perfect manner than has hitherto been possible with the three-way cock or brake-valves formerly used for this purpose, without much personal skill from the operator. It mechanically measures the required volume of air to be discharged from the train-pipe when applying the brakes for ordinary stoppages, and is equally efficient on short or long trains. When the handle 8 (*fig.* 2) is in "position for releasing brake," air-pressure from the main reservoir entering the brake-valve at *X* passes through "supply-ports" (*a*, *b*), thence upward into the cavity *c* in the under surface of the rotary valve 13, then through "direct application and supply-port" (*l*) to the train-pipe at *Y*. While yet in this position, port *j* (*fig.* 3) in the rotary valve and port *e* in its seat are in communication, and air passes into the chamber *D* above the piston 17, thence through port *s* to a small reservoir, which is usually suspended under the right running-board of the engine, pipe-connections being made therewith at *T*. This reservoir serves the purpose of giving increased volume to the chamber *D*. The handle 8 now being placed in "position while running," direct communication between the train-pipe and the main reservoir ceases, and port *j* is brought opposite feed-

port *f*, through which main-reservoir-pressure now passes to the under side of the "feed-valve" 21, which is held to its seat by a "feed-valve spring" (20) having a resistance of about twenty pounds. When this additional pressure is accumulated in the main reservoir, the "feed-valve" 21 is forced open, the pressure passing thence through "feed-port" *f'* to port *l* and the train-pipe. Pressure is maintained in chamber *D* (*fig.* 2) through port *l*, cavity *c*, and "equalizing port" *g*, thus equalizing the pressure on top and under piston 17, the stem of which, forming a valve, is seated in the position shown in the "bottom-cap" 5, and permits the escape of air from the train-pipe to the atmosphere through ports *m* and *n* when raised from its seat.

Locomotive Performances.—Strength, speed, safety, and economy are the principal features demanded of a modern locomotive, but the public seems to be more directly interested in the matter of speed than in the other features. It may be interesting in this connection to note some of the recent locomotive performances upon both sides of the Atlantic. Not long ago there was a race between the "Flying Scotchman" and the "West Coast Flyer" from London to Edinburgh, in which 400 miles were covered by the winner in seven hours and twenty-five minutes, or an average of over 53½ miles an hour.

One of the fastest runs in the United States was on the West Shore Railroad from Buffalo to New York, July 9, 1885, when 426 miles were covered in seven hours and twenty-seven minutes, the greater part of the run being made at the rate of forty-five seconds per mile, or from 70 to 83 miles per hour. Several miles were made at the rate of 78 miles per hour, one at 84 miles, and the next, between Genesee Junction and Chili, at 87 miles. Engines were changed at Buffalo, Newark, Frankfort, and Coeymans. In the same year, 11 miles were made over the same road in five hundred and twelve seconds, or 74 miles per hour, three of the miles being made at 80 miles per hour.

On the New York Central Railroad, August 8, 1886, a newspaper train with two cars weighing sixty tons was run from Syracuse to Buffalo, 148.7 miles, in one hundred and thirty-six minutes, being drawn by Rogers engines with one change.

June 1, 1876, the Jarrett-Palmer train ran from Jersey City to San Francisco in half time, or three and a half days, running to Pittsburgh, 438½ miles, in ten hours and five minutes, despite the Alleghanies; Pittsburgh to Chicago, 458.3 miles, eleven hours and six minutes—an average of 42.1 miles—including twenty-five stoppages and four changes of engines; Chicago to Council Bluffs, 491 miles, eleven and a half hours, or 42.6 miles an hour; and from Omaha to Ogden, 1032.6 miles, twenty-four hours and fourteen minutes. The entire run was made with nineteen changes of engine, there being seventy-two stops, and the running-time for 3313½ miles being eighty-four hours and seventeen minutes—an average of 40 miles an hour.

March 10, 1890, the Pennsylvania Railroad ran a special, known as

the "Aunt Jack" train, from Jersey City to Washington, D. C., 225 miles, in four hours and eighteen minutes. Change of engines was made at Gray's Ferry, Philadelphia, which required a stop of four minutes, the actual running-time being four hours and fourteen minutes.

Street- or Road-locomotives.—Leaving out of consideration the unsuccessful attempts, made even before the introduction of railroads (as already mentioned in the brief historical sketch), to construct a street-locomotive or steam-wagon, and the efforts in this direction by Dr. Robinson and by Watt (1759) and by Cugnot (1769), as well as the rather more successful construction by Evans referred to under railroad-locomotives, the history of the subject to be discussed here begins only about 1830. It would seem as though the construction of a street-locomotive should have offered no difficulties ten years after George Stephenson had developed his railroad-locomotive. But the uneven street, even the smoothest macadamized road, and still more the ordinary country road, differ so entirely from a solid and level railroad, with but slight grades and curves and constructed especially for locomotive service, that very peculiar and unexpected difficulties had to be overcome. But those who can comprehend the enormous pressure exerted by the driving-wheels of a railroad-locomotive against the unyielding iron or steel rails to produce the adhesion on which depends the motion of the entire machine, will approach with hesitation the solution of the problem of moving a wagon or a traction machine by wheel-tires pressing against a comparatively soft and yielding street surface.

Ice-locomotive.—On the smooth, even surface of ice success seems more possible, and the locomotive tried on the Neva and shown in Figure 3 (*pl.* 104) was not a total failure. It is constructed much like a railroad tender-engine, with water-tanks saddled over the boiler, but instead of truck-wheels is provided with sled-runners, and the driving-wheels have their peripheries set with sharp points. But the brittleness of ice remains an obstacle to running often over any given track, which becomes more and more damaged by the points in the tires. Besides, the sphere of availability is limited. Since 1862, when this ice-locomotive was invented, nothing further has been heard of it.

Dragging-track Locomotive.—Long before this (1846–1854), Boydell had endeavored to overcome the difficulty of the soft ground by a dragging track. As shown in Figure 6 (*pl.* 105), the track is pulled along by two driving-wheels moved by toothed gears. It consists of six flat pieces fitting into one another and loosely bolted to the driving-wheels. These pieces are successively laid by the engine itself in front of the driving-wheels. Although on a dirt road or in a field these flat pieces do not sink so deeply into the ground as would the driving-wheel alone, there is a greater tractive adhesion than the wheels would have on the ground. Guidance is effected by a truck with a steering-wheel, placed in front of the smoke-box. But, notwithstanding many favorable results, this locomotive is available for only a narrow sphere of usefulness, and, on account of its slowness, high price, and great cost of running, as well as the fre-

quent repairs required by the ingenious although complicated mechanism, it cannot compete under usual circumstances with the ordinary vehicle.

Traction Locomotives.—In 1862 there was tried another system, which depended simply on the friction of the tires on the street surface. The tires were rough or provided with projections and cross-grooves, or were entirely smooth, but almost as wide as the rollers used on macadamized roads. Figure 5 (*pl.* 105) shows another type. Close behind the boiler is the driving-axle, which is turned (as in locomobiles) by the single-cylinder engine on the top, a sprocket wheel and chain gearing being employed, while a steering-truck is arranged in front.

Schwarzkopf's Traction Locomotive.—At the Hamburg exhibition of 1862, the locomotive by Schwarzkopf of Berlin gained the victory over all other traction engines. This, with car attached, is shown in Figure 2. It differs from the preceding one in being provided with springs on the driving-axle as well as on the running-axle, and in having a twin link-motion steam-engine. Both distributing motions—borrowed, of course, from the railroad-locomotive, but not sufficiently appreciated by former inventors of traction engines—have considerably contributed to the attainment of a favorable result. The motion, however, is not effected directly, as with the railroad-locomotive, but through toothed-wheel gearing (seen to the left, under the boiler) placed between the engine and the driving-axle, while steering is effected by a chain-pulley (visible to the right, under the front car) turning the running-axle, which is provided with small wheels. With a speed of one (German) mile per hour the running expenses of Schwarzkopf's traction locomotive, with from five to six loaded cars attached, amount on an average to three pfennige per hundredweight per mile, inclusive of wear and tear and of interest on the cost of from 7000 to 8000 thalers ($5000 to $6000). This includes the wages of the crew and tollage. The weight of the locomotive is from 9000 to 10,000 kilogrammes (10 to 11 tons), and the maximum power from twenty to twenty-five horse-power.

In Figure 4 it will be seen that the internal arrangement of a street-locomotive, as regards the boiler, corresponds with that of a locomobile (*pl.* 96, *fig.* 3), the fire-box with the grate (omitted in the Figure) being surrounded by a vertical water-leg (seen to the left). The further arrangement consists of a group of narrower smoke- or fire-flues in a horizontal cylindrical boiler and a smoke-box (seen at the right) carrying the stack. Street-locomotives being tender-engines, a water-tank is provided under the engineer's place (at the left), with the driving-axle between it and the boiler. In this locomotive the engine, with its link-motion, is under the boiler, and the mechanism required for guiding the small front wheels is carried through the smoke-box, so that it can be managed from the foot-board by a horizontal shaft and screw-wheels.

Steam-carriages.—In 1824, David Gordon patented an arragement (previously proposed) for fitting to a steam-engine a set of jointed legs in imitation of the action of a horse's feet. In the same year, Burstall &

Hill made a steam-carriage in which the engine was like Evans's, except that its cylinder was at the end of the beam and the connecting-rod in the middle.

In 1827, Gurney built a steam-carriage which worked for about two years in and around London, one of its trips covering eighty-five miles in ten hours, including all stops. In 1828 he built a steam-carriage having a sectional boiler. Its cylinders were horizontal and the valve-gearing was driven by an eccentric on the rear axle. The link was moved by a cord running from the driver's seat. There was a separator to dry the steam, a forced draft, and a feed-heater; and the valve cut off the steam at about one-half stroke.

In 1829, Anderson and James built a road-engine which weighed three tons and carried fifteen passengers on a rough gravelled road at from twelve to fifteen miles per hour. The same year Hancock built a road-engine with a boiler consisting of a collection of flat chambers with boiler-plate sides, the chambers being connected by tubes and stays. In 1831 he placed a steam-carriage on the road between London and Stratford, where it ran regularly; while at the same time Dance had one running between Cheltenham and Gloucester, where it ran back and forth thirty-five hundred miles, running the nine miles, the distance between the two places, in fifty-five minutes, and meeting with but one mishap, which was the result of malice. Ogle & Summer's steam-carriage ran from thirty-two to thirty-five miles an hour, carrying two hundred and fifty pounds of steam. Hancock's "Infant" of 1831 ran from Brighton to London, carrying a party of eleven, at from nine to fifteen miles per hour.

Hancock's "Autopsy" of 1833 went about the streets of London at all times without difficulty. It is shown in Figure 1 (*pl.* 105). By this time there were about twenty steam-carriages and traction road-engines running in England, where good roads had aided the inventors and builders; but hostile legislation checked the advance of this method of conveyance.

The external appearance of a steam-carriage according to Rickett's construction—that is, a carriage driven by steam and adapted for the transportation of persons—is represented in Figure 7, while the internal arrangement of a steam-omnibus can be seen in Figure 3. On the left is a seat for the stoker in front of the boiler, which is similar to that of a locomotive, but considerably shorter. On the right over the running-axle is a seat for the driver, who controls the throttle and reverse lever in front. In the centre on the tender are upholstered seats for eight persons, and an awning or roof can be arranged, as indicated by the dotted lines. An engine under the seats acts through a transmitting shaft and gear-wheels on the driving-axle (on the left) placed under the horizontal portion of the boiler.

No steam-carriage, steam-omnibus, street-locomotive, or traction engine has been invented which could justify the supposition that it could enter into a general, effective competition with the prevailing mode of carriage. Even street-cars driven by ammonia-engines, which at one time created a

great sensation in America, seem to have been abandoned, notwithstanding the satisfactory experiments by General Beauregard.

Experimental machines have been constructed in which traction has been obtained by pedals or feet which pressed against the ground as an abutment, these being given an alternating movement by which the wheeled carriage bearing the motor was propelled. The feet were raised and lowered and the legs to which they were attached were given a backward and forward motion. There is no question about the traction thus obtained being much in excess of that obtained by the adhesion of a metal tire to a metal rail, or of a metal, wooden, or rubber tire working upon an ordinary road surface; but the machine itself is of necessity burdened with faults of design, construction, and operation, and the device is not worthy of being called practical.

4. GAS, CALORIC, AND OTHER THERMO-DYNAMIC MOTORS.

Gas Motors.—Before the invention of the steam-engine Papin experimented with the gases of gunpowder as a motive substance (see p. 244), and it will be readily understood that after the invention of the application of steam the employment of other vapors than those of water, and of other gases than those of gunpowder, would suggest itself. This idea has been maintained up to the present time, and periodical efforts are made toward its realization.

In 1791, John Barber took out a patent for a rotary reaction sphere, like that of Hero of Alexandria (see p. 240), into which, from a retort furnace, also patented, there was to be introduced gas (evolved from wood, coal, or other hydrocarbons) which by burning, expanding, and escaping would cause the sphere to rotate. Three years later (over a hundred years after Papin's experiment with Guericke's cylinder, and after Newcomen's machine had been working for eighty years) Street patented a machine, consisting essentially of a Guericke and Papin cylinder, in which, instead of steam, there was to be used an explosive mixture of carburetted hydrogen-gas and air. In 1799, Lebon invented a machine, like a double-acting steam-engine, in which a mixture of gas and air was ignited by an electric spark. In 1823, Brown patented the application of the vacuum produced by the contraction of the exploded gas instead of by its direct action; he also patented an arrangement for cooling the cylinder by water. To ignite the explosive mixture, Wellmann Wright in 1833 used a gas-flame instead of the electric spark. His machine was direct and double-acting, the air and gas being forced in by two pumps and the proportion of the mixture being regulated by the working of the machine itself through a ball-governor. The flame-igniting system most widely used at present was invented by Barnett in 1838; he also invented the compression system so largely used. His first engine, which acted upon the up-stroke only, required a pump to take out the exhaust gases. Newton in 1855 ignited the gases by a piece of red-hot metal when the piston left uncovered a recess in which this piece of metal was placed. Barsanti

and Matteucci produced in 1857 an engine having a free piston in a long vertical cylinder, the explosion giving the piston considerable velocity, which, on the down-stroke only, was imparted to the fly-wheel. But it was not until 1858 that the illuminating-gas motor of Degrand and Hugon, followed in 1860 by that of Lenoir, gave practical gas-engines. The efforts of Otto and other inventors placed these motors in competition with the steam-engine, as they could be employed where a great amount of power was not required or was needed only intermittently, or where the presence of the steam-boiler or the necessity for a skilled attendant was objectionable. In impelling its piston, the gas-engine or gas motor uses the force produced by the combustion of solid, liquid, or gaseous fuel in or with atmospheric air, the greater volume of the gaseous products of combustion, as compared with that of the substance burned and the air with which it combines, being due partly to purely chemical change of condition and partly to the heat of combustion.

Lenoir's Gas-engine (*pl.* 106, *fig.* 1) has essentially the construction of a horizontal double-acting high-pressure steam-engine. There is a Ruhmkorff electric apparatus, from which wires run into the cylinder, and after the crank leaves the dead centre at each rotation there passes between the wires a spark which explodes the mixture of gas and air. There are four gas-passages and two valves, for admission and exhaust, while a jacket for water circulation keeps the cylinder comparatively cold.

The Otto-Langen Gas-engine of 1864, shown in Figure 2, consists of a vertical cylinder, which supports the wheel and shaft and is surrounded for about one-half its height by a water-jacket. In its interior arrangements it is much like the Papin apparatus (*pl.* 80, *fig.* 7), whose action it resembles in that an ignited mixture of gas and air forces the unloaded piston upward in the cylinder, which is open on top, and by its subsequent contraction permits the pressure of the atmosphere to do the actual work of driving the fly-wheel, there being a rack on the piston-rod, working in a pinion, and a ratchet motion which allows the piston and the rack to overrun the pinion during the explosion and to take hold of it on the down-stroke. In the Otto-Langen engine the explosions are utilized, in the Hugon and in the Lenoir they are absorbed, by dead masses. In the Otto-Langen machine the gases are ignited by a gas-flame.

The Otto Gas-engine of 1890 (*pl.* 106, *fig.* 3)—a development of the type of 1876—has a cylinder open at one end and having in it a piston connected to a fly-wheel by a piston-rod and a connecting-rod. Between the closed end of the cylinder and the piston there is a considerable space, wherein a charge of gas and air, drawn in by an entire out-stroke of the piston, is compressed. The openings for the inlet of this charge and its subsequent ignition are at the closed end of the cylinder, and these functions are controlled by a slide-valve found at that end. There is also a lifting-valve, to effect the exhaust of the burned gases after the combustion has occurred. The operation is as follows: On the out-stroke of the piston gas and air are drawn in, which on the return-stroke are compressed into the space

referred to. This is done by turning the fly-wheel by hand, or, in case of large machines, by a smaller engine. When compressed, the charge is ignited and there is developed the pressure, which propels the engine during the subsequent stroke. Returning by the momentum of the fly-wheel, the piston expels through the exhaust-valve the products of combustion. When the speed is excessive, a governor prevents a fresh charge of gas from entering the cylinder, the air alone being admitted, thus varying the number of effective charges and the gas-consumption in proportion to the load upon the engine. Ignition is effected by various methods, according to the size of the engine, etc. Flame-ignition as well as an electric spark or an incandescent tube is used. The charge ignited is so constituted that the richest part, which will enter into combustion rapidly, is nearest the point of ignition.

Gas-motors proper differ from all other heat-engines in using as a motive fluid atmospheric air and as a mode of heating it atmospheric gas. So far the heating is accomplished by mixing them before ignition, but for all that it is the air, not the gas, which is the working fluid. This is heated and the heating fluid is burned in the cylinder instead of in a separate vessel.

Air being a fluid much poorer than water for conveying heat, the gas- and the hot-air engines are in this respect at a disadvantage; but gas-motors have the advantage over hot-air engines (p. 303) in the greater temperature that can be given to the air by explosion than by mere heating in contact with metal plates.

The high temperatures attained in the cylinders of gas- and hot-air engines make it necessary, in order to prevent destruction of the metal, to employ larger cylinders in proportion for a given power than in a steam-engine, and their friction is much greater. The gas-engine can employ a cooling-jacket without loss of heat for working purposes; the air-engine cannot do so.

The gas-engines of the present day may be divided into those igniting at constant volume without previous compression, those igniting at constant pressure with previous compression, and those igniting at constant volume with previous compression. The first type is the simplest.

In 1860 the efficiency of the gas-engine was only about four per cent. of the theoretical maximum; in 1886 it had risen to eighteen, and now it is probably about twenty per cent. In this it has surpassed the steam-engine, which gives out only from twelve and a half to fifteen per cent. of the possible theoretical maximum. At present it takes about 20 cubic feet of gas per hour for each indicated horse-power. This could be reduced by complete expansion to the atmospheric pressure to about 15 cubic feet.

A great disadvantage of the gas-motor at present, as compared with the steam-engine, is the greater cost of each unit of heat supplied in the form of coal-gas than that of each unit supplied in the form of coal. A good gas-producer giving gas stable and free from tar is much needed. To

improve any gas-motor, it should be made double-acting, and should be governed by diminishing the power of the impulses instead of their frequency.

Hot-air Engines, or so-called "caloric motors," use as a motive fluid ordinary air, usually heated in a vessel separate from the working cylinder. One was constructed in 1827 by John Stirling, and in 1833 the famous Ericsson experimented in this direction, but succeeded only in 1848. In 1853 he produced a marine hot-air engine intended to supply six hundred horse-power; it, however, indicated only three hundred horse-power.

Roper's Caloric Engine.—Among engines driven by the gases of combustion without explosion or compression is Roper's engine, which is well known in America, and is illustrated in Figure 5 (*pl.* 106). Upon the cylindrical fire-box there is placed the working cylinder, and upon or alongside of this is the compressing cylinder. The air is forced into the furnace through the descending pipe, shown at the back, and after having been mixed with the products of combustion is forced into the working cylinder, where it drives the piston upward by its expansion. After ignition the fire-box is closed tightly. The disadvantages of this system are that the heat of good combustion is from 1000° to 1300° Fahr., that the excessive amount of air required will prevent proper combustion, and that cinders will be passed into the working cylinder. The use of coke does away in great part with the latter objection; gas offers a still better expedient in this respect.

The Wilcox Motor, shown in Figure 4, consists of two cylinders suspended for half their height in a furnace, the one in front being the working cylinder and the one behind it the feeding cylinder. The bottoms of these project conically into the interior, and after being heated by the products of combustion in the fire-box heat the air contained in the cylinders. The lower ends of the massive pistons are hollowed out, so as to correspond with the form of the bottoms of the cylinders, while the upper ends are level planes. The piston in the working cylinder acts only during its ascent, being driven down by the action of the fly-wheel. The piston in the feeding cylinder is moved by a crank placed 75° from the working-cylinder crank. The pump draws fresh air into the feeding cylinder and presses the heated air into the working cylinder. Between the two cylinders there is a "generator" (wrongly so called), which consists of several layers of wire nets or metallic sieves; its function is to withdraw from the air escaping from the working cylinder a portion of the heat in that air, and to transfer it to new air forced through by the feeding cylinder.

The disadvantage of the hot-air motor as compared with the steam-engine is that water takes up only $\frac{1}{1700}$ of the space occupied by the steam raised from it at atmospheric pressure, so that while a comparatively small boiler and pump may serve for an engine of great power, in the hot-air engine it is necessary to pump into the motor air of nearly as great a volume as is needed in the cylinder; that is, in the steam-engine the pump is very small as compared with the boiler, while in the hot-air engine it

must be nearly or quite as large as the working cylinder. This may be readily seen in Figure 4 (*pl.* 106).

Only those hot-air engines which permit the use of air considerably compressed act economically. If the air be compressed by the pump, its temperature will be considerably increased; by reason of this it can absorb very little heat for the purpose of mechanical exhaustion. As it is not well for the cylinder that the air have a temperature of over 300° Cent. (on account of the difficulty of getting a lubricant to stand such high temperatures), the limit of practical ability of exhaustion is soon reached, and the necessary size for a given horse-power is very great.

Ericsson's Hot-air Engine.—In 1860, Ericsson constructed a hot-air engine, such as shown in Figure 6, consisting of a single horizontal cylinder projecting (to the right) into a furnace, whose fire-doors and the channels surrounding the cylinder-like jackets are seen in the Figure. The cylinder is both a working cylinder and a pump cylinder, having two pistons, which by a very ingenious crank-and-lever mechanism are so moved toward and from each other that the drawing in of air, its compression, heating, and expansion, take place in the order required for proper work. While a ball-governor is provided, a heavy fly-wheel serves to steady the motion and by its momentum to force back the piston. The trouble with this type was that it was soon destroyed by the heat and required too many repairs, the metal fire-box burning out, and also tending to destroy the cylinder and the piston.

The Ericsson Improved Hot-air Motor (*pl.* 107, *fig.* 5), as at present built for pumping, is a single-cylinder engine in which are two pistons, one called the "main" or air-piston (*b*), which receives and transmits power, and the other the "transfer-piston" (*c*), whose office is to transfer the air contained in the machine alternately and at the proper time from one end of the cylinder (*d*) to the other.

The cylinder is provided at its upper end with a water-jacket (*x*), through which all the water passes on its way from the well to the tank. This jacket keeps the upper end of the cylinder cool, while the lower end is exposed to the fire and becomes as hot as it is practicable to make it. By the peculiar arrangement of connections between air- and transfer-pistons, the proper relative motions between these pistons are obtained. The operation is as follows: After the lower end of the cylinder has been sufficiently heated, the engine must be started by hand by giving it one or two revolutions. The air contained in the machine is first compressed in the cold part of the cylinder, and is then transferred to the lower end, where it is instantly heated and expanded, thus furnishing the power. This, like all other hot-air engines, is only single-acting. The momentum of the fly-wheel continues the rotation until it receives an additional impulse by the repetition of the above-mentioned conditions, which occur once in every revolution. The same air is used continuously, and is cooled, compressed, heated, and expanded in regular order.

The Rider Compression Hot-air Engine, as arranged for pumping, is

shown in Figure 4 (*pl.* 107). The compression-piston *A* extends downward to the base of the engine, closely fitting the compression-cylinder *B*, which also extends downward nearly to the bottom of the cooler *K*. The lower part of the compression-cylinder *B* is sufficiently smaller than the inside shell of the cooler *K* to form a thin annular passage for the air, which becomes cooled on its way to the bottom, and through which passage it flows on its way back to the heater. The power-piston *C* likewise extends downward into the heater *E*, which in shape resembles the bottom of a champagne-bottle—that is, rising in the centre and presenting to the action of the fire a narrow annulus all around the bottom. Within this heater is the "telescope," a thin iron cylinder about 1/4 of an inch less in diameter than the interior of the heater. This cylinder is fitted to the interior of the power-cylinder *F*, and extends nearly to the bottom of the heater. Its office is to cause the air which flows from the compression-cylinder to be presented in a thin sheet all around the interior surface of the heater, and particularly at the lower and hotter portion. The same air is used continuously, as there is neither influx nor escape, the air being merely shifted from one cylinder to another.

Between the compression-cylinder and the power-cylinder is situated the regenerator *D*, which is so placed between the cylinders as to be traversed by the air in its passage backward and forward. *O* is a check-valve which supplies any leakage of air that may occur. It is placed at the back of the engine, but it is necessarily shown in the sectional cut on the side. The other portions of the engine are readily understood by inspection of the Figure.

The operation of the engine is, briefly, as follows: The compression-piston *A* first compresses the cold air in the lower part of the compression-cylinder *B*, when, by the advancing or upward motion of the power-piston *C* and the completion of the down stroke of the compression-piston *A*, the air is transferred from the compression-cylinder *B* through the regenerator *D* into the heater *E* without appreciable change of volume. The result is a great increase of pressure, corresponding to the increase of temperature, and this impels the power-piston up to the end of its stroke. The pressure still remaining in the power-cylinder and reacting on the compression-piston *A* forces the piston *A* upward till it reaches the top of its stroke, when, by the cooling of the charge of air, the pressure falls to its minimum, the power-piston descends, and the compression again begins. In the mean time, the heated air, in passing through the regenerator, has left the greater portion of its heat in the regenerator plates, to be picked up and utilized on the return of the air toward the heater.

Sun-motors.—The name "sun-motor" is employed to designate an apparatus by which the heat of sun-rays is concentrated upon a generator (steam-boiler or other) which furnishes steam or other motive vapor to an engine. It differs from an ordinary "self-contained" motor merely by the addition of a reflector which concentrates the rays upon a spot or strip on the blackened surface of the generator, and which has a clockwork to

make it "follow the sun." For many centuries the idea of utilizing the sun's heat in pumping water or in driving machinery has been a favorite one with inventors. Euclid, Archimedes, Hero of Alexandria, Solomon de Caus, Buffon, De Saussure, Ducarla, Pouillet, Fauchot, Ericsson, Mouchot, and others experimented in that direction. In 1861, Mouchot produced a "heliopompe" or "sun-pump," followed in 1865 by several others; and Ericsson experimented for twenty years prior to 1883, when he produced what may be said to be his first working engine. His experiments were continued up to his death in 1889, and it is to be hoped that some other able experimenter may push them to a desirable conclusion.

Mouchot's Sun-engine, exhibited in Figure 3 (*pl.* 107), consists of a masonry pedestal (*A*); of a stirrup-shaped cast-iron support (*B*) turning on a shaft by which, in order to face the sun squarely and get the full effect of its rays, the apparatus is given an elevation relative to the latitude of the spot on which it is erected; of a sector (not seen in the Figure) fitted on a shaft (*b*), by which the apparatus is made to follow the diurnal movement of the sun in order that the effect may be continuous and the mirror (*c*) not left partly in its own shadow; of a framework (*E*) to which the boiler and the skeleton of the reflector are attached; of a plate-iron tubular boiler (*F*), which is surrounded with a glass jacket (*G*) to aid in concentrating the heat, and which is provided with a steam-dome (*H*), a safety-valve (*I*), and a steam-gauge (*J*); of a sector (*M*) worked by a screw (*m*) for giving the latitudinal inclination; of a train of geared wheels actuated by a handle (*n*) for the diurnal movement sector; and of a sector (*S*) fitted on a shaft (*r*), and worked by a screw (*o*) to alter the position of the boiler and the reflector according to the different solstitial angles in summer and winter. The extreme diameter of the reflector was about 16.4 feet; the area of the opening, therefore, was about 65 feet. The boiler—nominally, three horse-power (?)—weighed, with its accessories, four hundred and forty pounds. It had an extreme length of 8.20 feet and a capacity of forty-four gallons or 3.53 cubic feet, 1.059 cubic feet of which was steam space, and the remainder, or 2.471 cubic feet, water. The usual time required to get up steam varied with the intensity of the sun's rays, the state of the atmosphere, etc., and was generally one and a quarter hours for the first and eight minutes for every succeeding fifteen pounds pressure; and adopting the data of September 22 as the result of mean autumnal influence and as a fair criterion, we find that on that day a steam-pump connected with the apparatus was lifting between 2000 and 3000 litres, or 4600 gallons, per hour for a short time with a steam-pressure of three atmospheres. The pressure at times rose as high as seven and eight atmospheres; but it was quite apparent that, owing to the lateness of the season or to the imperfections of the boiler, which by allowing the steam to collect on the inner surface of the glass jacket prevented the passage of the rays, or to the leaky state of the pump and consequent loss of power, or to whatever fortuitous circumstances it may be ascribed—although the initial pressure at starting was six and a half atmospheres—

it sank so rapidly—namely, at the rate of one atmosphere in every three minutes—that no reliance could be placed on the experiment as illustrating the practicability of the principle.

Ericsson's Sun-motor (1883) employed a portion of a parabolic cylinder as a reflector to collect and concentrate the rays of the sun; this reflector was in fact a trough, its bottom or well being composed of wooden staves which were supported by ribs of parabolic curvature, and on which there were reflecting plates of glass silvered on the under side. The apparatus is shown in perspective in Figure 1 (*pl.* 107); a part of it is shown in transverse section in Figure 2, where the direct and the reflected solar rays are shown by vertical and by diagonal lines. It is described by its distinguished inventor, the late Captain John Ericsson, as follows: "It will be seen that the trough, 11 feet long and 16 feet broad, including a parallel opening in the bottom 12 inches wide, is sustained by a light truss attached to each end, the heater being supported by vertical plates secured to the truss. The heater is $6\frac{1}{4}$ inches in diameter, 11 feet long, exposing $130 \times 9.8 = 1274$ superficial inches to the action of the reflected solar rays. The reflecting plates, each 3 inches wide and 26 inches long, intercept a sunbeam of $130 \times 180 = 23,400$ square inches' section. The trough is supported by a central pivot round which it revolves. The change of inclination is effected by means of a horizontal axle (not seen in the Figure), the entire mass being so accurately balanced that a pull of five pounds applied at the extremity enables a person to change the inclination or to cause the whole to revolve. A single revolution of the motive engine develops more power than is needed to turn the trough and to regulate its inclination so as to face the sun during a day's operation.

"The motor is a steam-engine (*fig.* 1), the working cylinder being 6 inches in diameter with 8 inches' stroke. The piston-rod, passing through the bottom of the cylinder, operates a force-pump of 5 inches' diameter. By means of an ordinary cross-head secured to the piston-rod below the steam-cylinder and by ordinary connecting-rods, motion is imparted to a crank-shaft and fly-wheel applied at the top of the engine frame; it being the object of this arrangement to show the capability of the engine to work either pumps or mills. It should be noticed that the flexible steam-pipe employed to convey the steam to the engine, as well as the steam-chamber attached to the upper end of the heater, has been excluded in the illustration. The average speed of the engine during the trials (1883) was one hundred and twenty turns per minute, the absolute pressure on the working piston being thirty-five pounds per square inch. The steam was worked expansively in the ratio of 1 to 3, with a nearly perfect vacuum kept up in the condenser inclosed in the pedestal which supports the engine-frame."

Vapor-engines.—Strictly speaking, there is no such thing as a vapor-engine as distinguished from a gas-engine. Almost any inflammable or explosive vapor can be used in an ordinary gas-engine with but very little

change, the difference between a vapor and a gas being largely dependent upon temperature.

Ether-vapor Engines.—In seeking other motive fluids than water cheapness was kept in view so long as it had to be applied to a machine from which it must escape after being used. Water, air, combustion gases, and even illuminating gas, answered the requirements better than most other substances. But, as there are steam-engines in which the steam is condensed and used repeatedly, and caloric engines in which cooling arrangements permit the repeated use of the same fluid, the question of cheapness of motive fluid becomes less important. For such closed motors ether, bisulphide of carbon, and ammonia have been used. Ether evaporates at 33° Cent. and acquires a tension of nearly nine atmospheres at 100°, while saturated steam at this temperature has only one atmosphere. Hence, by using the exhaust from a steam-engine, ether may be evaporated at a considerable tension and its vapor be used in an engine constructed like the steam-engine and placed alongside thereof, so that this auxiliary motor is practically worked without any fuel. Tremblay, Delaporte, Tellier, and others have produced engines upon this principle. The chief objection to ether as a motive fluid is due to the impossibility of preventing leaks, and, the material being both expensive and highly inflammable, the objection is a serious one. The same may be urged against alcohol, naphtha, etc. Bisulphide of carbon seems to be the most promising fluid for use in this connection.

Oil-engines.—Almost any gas-engine can be used with oil as a motive fluid by adding a pumping attachment by which the oil can be "atomized" or sprayed so as to enter the igniting chamber in such a highly-divided state as to be explosive when mixed with the proper proportion of air.

Compressed-air Motors.—Any plain steam-engine can be run with compressed air if care be taken to have the air dry, so that the exhaust orifice will not become clogged by the snow formed when moist air is released from compression. It must be remembered, however, that air will not work expansively like steam. Most rock-drills can be driven either by compressed air or by steam. As a means of transmitting power to a distance, compressed air has the advantage over steam, as the air loses nothing in force by reason of radiation from the containing pipes, and in mines it not only aids in ventilating, but has the advantage of not rotting the timbers as does the exhaust steam.

Aëro-steam Engines.—Compressed air has been tried as an auxiliary to steam for the purpose of re-evaporating the water formed by radiation and internal condensation; the principle on which it acts being that recently-compressed air at a given pressure has a higher temperature than ordinary steam at the same tension. The heat of compression, instead of going to heat the containing vessel, is largely absorbed by the water held by the steam. In this respect the air has the effect of a superheating jacket; but its use calls for increased size of cylinders and pipes. (R. G.)

II. APPLICATION OF POWER.

I. TRANSPORT MACHINES.

Classification.—The object of transport machines is to effect or facilitate the transfer of materials from place to place. Such mechanical appliances may be divided primarily into four classes, namely: (1) those for the transfer of solids, (2) those for the transfer of liquids, (3) those for the transfer of gases, and (4) those for the transfer of power. Appliances for the transfer of solids may be subdivided into (1) those acting in a horizontal plane, such as vehicles serving as carriers for goods and heavy loads; (2) those acting in a vertical plane, such as tackles, derricks, cranes, elevators, etc.; and (3) those whose action combines both directions of motion. Appliances for the transfer of liquids and gases naturally move such bodies without regard to direction. Appliances for the transmission of power are to be classified as (1) those by which power is transmitted through direct mechanical motion, as in gearing, shafting, belting, etc.; (2) those in which the power is conveyed through water and gases and which have a limited application; and (3) those which transmit power by first converting it into electrical force, and then by the reconversion of the electrical force into mechanical power. The following section, therefore, will treat not only of specific transfer machines, but also of their combinations with carriages and motors.

1. Transport Machines for Solid Bodies.

Primitive Means of Transport: The Sled.—The first recourse of man for conveyance was his own back and limbs, and in some countries this method is still employed. The dog, the horse, the ox, the camel, the dromedary, and the elephant have all been subjected to man's control for purposes of burden or of draught. The first mechanical means of transport was doubtless the sled. It was employed by the Egyptians in the transfer of large masses of stone. In one of their sculptures is represented a colossal statue on a sled drawn by one hundred and seventy-two men in four rows, each row consisting of forty-three men. On the pedestal at the front of the sled stands a man with a vase, from which he pours a liquid, probably oil, for the purpose of lubricating the ways over which the sled moves. Standing on the knee of the statue is a man who appears to be clapping his hands as a signal for a concerted pull. Relays of drawers walk behind the sled, and following these are men carrying vases containing oil, or perhaps water, and other men with implements for some purpose, while supervisors or task-masters bring up the rear. The ropes for drawing the sled are all attached to its front. At Koyunjik a bas-relief shows that the sled was also adopted by the ancient Assyrians for removing the colossal figures from the quarry where they were hewn to the place they were intended to occupy.

Ctesiphon's Transport Machine.—Ctesiphon, when he wanted to convey the shafts of the columns from the quarry to the temple of Diana at Ephesus, being unwilling to trust to carriages on account of the weight of the shafts, or to hazard the sinking of the wheels on account of the softness of the fields in the way, employed the ingenious contrivance exhibited in Figure 1, *a* (*pl.* 108). It consisted of four pieces of timber (*A*, *B*, *C*, *D*), two (*A*, *D*) interposed transversely on two (*B*, *C*), equal to the length of the shaft of the column. At the ends *A*, *D* of the shafts he inserted dovetailed iron gudgeons (*chodaces*), which were secured with lead and fixed bearings (*armillæ*) in the timbers for the gudgeons to revolve freely. The shaft, which revolved as does an agricultural roller, was drawn by oxen by means of ropes attached to the poles *F*. Figure 1, *b*, shows the vehicle for transporting an architrave.

Vehicles: Carts.—The origin of two-wheeled vehicles is attributed to Erechtheus (1400 B. C.), but they are known to have been in use as early as 2000 B. C. The first forms of wheeled vehicles were doubtless carts and chariots. Carts drawn by oxen were used by the Scythians in the time of Herodotus (450 B. C.); the body of the cart was either permanent or detachable; if detachable, it constituted a felt-covered tent-frame, which could readily be placed on or removed from the running-gear. The first wheels of vehicles were narrow sections cut from the trunk of a tree and immovably attached to the axle in the manner of the modern railway car-wheels. The Chilian cart of to-day is a primitive vehicle, whose wheels are discs sawn or chopped from a log and bored for the axle, to which a tongue or pole is secured; there is thus formed the frame of the bed, which is somewhat like a city dray. The modern dumping-cart for the removal of materials from excavations and for other purposes has the bed hinged to the axle, and is so contrived as to tilt and discharge the load when desired. For removing the earth excavated in constructing the foundations of his numerous bridges, the French engineer Perronet employed coupled carts running on rails. Each cart had a bed capable of holding a cubic yard of earth, and was so suspended from the axle that a part of the contents was below the axle and nearly balanced the load, so that the earth was easily dumped. In the rear of the forward cart-frame was a shackle by which the second cart was attached to the one in front; each cart, therefore, could be separately loaded and drawn into the regular track, along which the coupled carts were drawn by a horse.

Wagons.—The wagon, as applied to the transport of merchandise and heavy loads, has many forms. As above stated, the first forms of wheeled vehicles were ox-carts and chariots; the four-wheeled vehicle was much later. One of the Scythian wagons measured 20 feet between the low wheels; the axle was like a ship's mast, and the wagon was drawn by twenty-two oxen, eleven abreast. The high-wheeled wagon was derived from the barbarians. The perch or coupling between the fore and hind axles was added in the Middle Ages. The char of the fourteenth century (the state carriage of that period) was but a wagon whose shafts were

fastened to the wagon-body and the two axles fastened to the bed—an arrangement which must have made the wagon difficult to turn.

Dumping-wagons.—One of the arrangements for transport and dumping is the dumping-wagon. In this the bed runs back on rollers by power applied through a winch and ropes. By a reversal of the tackle the bed is replaced. A modification is the coal-chute wagon, in which the body by means of a mechanism actuating levers is so elevated that the coal can be discharged into chutes or troughs, and thus conveyed to the cellar.

Trucks.—The hand-truck is an efficient vehicle for removing single packages of considerable weight, and it is an indispensable auxiliary in warehouses, express-offices, etc. In its simplest form, the hand-truck consists of a flat rectangular, tapering frame of oak or other tough timber strongly fastened together by bolts, the main pieces of the frame being converted into curved handles at one end, and connected at the other end with a flat curved bar, which is so bent as to stand at an angle of about 45° with the plane of the frame-work. The frame or bed is mounted on an axle, and heavy wheels of small diameter placed a short distance from the bar-end of the bed; which arrangement gives the leverage necessary for loading weighty packages on the truck. With the handled end of the truck-frame in a nearly vertical position, the curved bar is inserted under the lower edge of the parcel—for example, a box—which is then tipped back against the bed, while at the same time the handles are depressed, so that by this means the article is lifted on the truck for conveyance to any desired place.

Wheelbarrows.—The first wheelbarrow, dating from as early as the thirteenth century, differed but slightly from the barrow now commonly employed. The varieties of wheelbarrows are as numerous as are the uses for which they are required, and according to their uses they are named—grading, garden, express, brick, dumping, porterage etc. barrows. In railway constriction the grading barrow is an efficient machine for removing the excavated earth. It has a small wheel, widely diverging handles, and a scoop-shaped body, so adapted as to dump on either side. The express barrow is a superior form of warehouse or baggage-truck for conveying heavy loads on a floor. The load is balanced on a central pair of wheels, while a wheel at the two ends restrains the oscillation within moderate limits. The Chinese barrow has but one large central wheel placed in the centre of the bed; the entire load rests on this wheel.

Conveyers.—For the horizontal transport of materials there are employed other mechanical means, such as conveyers, rope transmission, cranes, etc. The conveyer consists of a conduit in which is a continuous spiral blade around a horizontal axis, the rotation of which causes the screw-like blade to push forward the materials (grain, etc.) from the initial to the terminal points, similar to the operation of the Archimedean screw (page 327). Rope transmission may either be by a travelling wire-rope or by a stationary rope on which the loads (coal, ores, etc.) are suspended and moved by animal power; for example, the hay-trolley (page

187)—or by electricity. (See Vol. V. page 236.) Cranes and allied mechanisms, which primarily have a vertical movement, are more properly classed with hoisting apparatus, which will be described in the succeeding treatment of transport machines whose action is in a vertical plane and to a limited extent horizontal.

Gins.—Changes of location within a short distance vertically, or, more specifically, within a very narrow sphere of action, are effected by means of gins. These are portable hoisting-machines whose frames are tripods. One of the legs of a gin is movable, to permit of a variation in its angle of inclination, so as to adjust the height of its apex. For raising heavy weights a fall and tackle is employed, but in mining or in hoisting a bucket from a well there are provided a couple of pulley-blocks, one of which is suspended from the apex of the frame, the other being suitably anchored between the two permanent legs. By this arrangement the direction of the draughts of the rope is changed to a horizontal position, thus providing for the attachment of a horse or other motive power for raising the load suspended from the vertical rope. A contrivance similar to the gin is mentioned by Vitruvius.

Lifting-jacks.—With the simple transport machines must also be classed the various forms of lifting-jacks, which include the hand-screw and related implements, for lifting wagons requiring repairs or for uprooting tree-stumps. In a certain sense, these jacks take the place of the ordinary lever. Their mechanism consists of a rack actuated by a cog-wheel and a crank, or of a spindle which receives its motion by means of a screw in a threaded socket and is rotated by a lever (*pl.* 108, *fig.* 2), or, finally, of a mechanism consisting of a ratchet-wheel, click, and lever (*fig.* 3). By the apparatus shown in Figure 2 the load lifted by the vertical screw can be moved laterally by the horizontal screw; hence the machine is called a "traversing-jack." To this class of machines belongs the hydraulic jack (*fig.* 7). The iron tubular casing encloses an immovable piston or ram, a small plunger-pump, and a reservoir for liquids (water, oil), which are introduced to the reservoir through a screw-fitted opening at the top of the machine. The raising of the pump-lever on the outside permits the water to flow into the pump-cylinder, and the downward stroke of the pump-piston forces the water through a suitable valve into a lower cylinder, where the pressure it exerts on the head of the ram causes the upper or movable body to raise the weight placed either on its head or on its projecting foot. The lowering of the load is effected by allowing the fluid to flow back into the reservoir by means of a screw-valve between the upper and the lower chamber. Hydraulic jacks, of which there are several forms, produce the same effect as the hydrostatic press (*pl.* 9, *fig.* 9), whose construction differs from that of the former in that the pump is separated from the part containing the press-piston. There is, moreover, in the latter a press-frame, which so holds the mass that it may be compressed or from it may be expressed water, juices, etc. These hydrostatic presses, which must properly be classed with working machines, may, in fact, be used

for lifting large bodies, and hence may also be classed as transport machines. For example, all the tubes for Stephenson's railroad-bridge over the Menai Strait, each weighing over eighteen hundred tons, and more recently entire blocks in Chicago, have been lifted by means of such machines, the pumps operating them being worked by steam.

Tackles.—The simple pulley, which is secured to a fixed point and over which a rope or chain is passed, is not a lifting-machine, as it serves not so much for lifting as for changing the direction of the lifting-rope. When, however, it becomes a so-called "loose" or movable pulley, moving with the load to be raised, it becomes a mechanism, though one of a very simple construction. With its use double the load can be lifted with the same power, requiring, however, double the time. The combination of a movable and a fixed pulley or of several such pulleys is called a "tackle." By increasing the number of pulleys in a block any desired weight could be lifted by a given power were it not for the limit set by frictional resistance, together with the stiffness of the rope or chain; and this limit is so soon reached that the advantages of cheapness and simplicity are counterbalanced by the disadvantage of very slight efficiency.

In the older forms the pulley-blocks were made of wood (*pl.* 108, *fig.* 5), which in late productions has been largely superseded by iron (*figs.* 4, 6). The block farthest to the right in Figure 4 is so constructed as to admit of adjusting the rope to the wheel with greater facility than with the ordinary blocks.

The Differential Pulley (*fig.* 8) is a form of tackle which may be employed with great practical advantage. Its mode of operation corresponds with that of the differential windlass (*fig.* 10), which is known as the "Chinese windlass." On the same shaft are fixed two drums of different diameters, to which the two ends of a rope are fastened. The rope winds over the two drums, winding on one as it unwinds from the other; the effect thus gained is as the difference between the two drums—the smaller the difference, the greater the power and the less the speed. Upon this principle is constructed the differential pulley (*fig.* 8). A pair of pulleys of different diameters form the upper fixed block, and the lower pulley the movable block. To prevent the chain from slipping, the upper pulleys are provided with sprockets. The advantages of this form of tackle over other forms are that it can lift a comparatively large load without requiring much space and that it is inexpensive. It has, however, the disadvantage of opposing a greater frictional resistance to the lifting, thus making the raising of the load either more laborious or more time-consuming; but this disadvantage is partially compensated, inasmuch as the increased resistance of friction prevents the load from sinking when the chain is let go. To lift 2200 pounds with a traction of 22 pounds one hundred pulleys are required with an ordinary tackle, but only three pulleys are necessary with a differential tackle. This example, which is greatly in favor of the differential tackle, is, however, only theoretically correct—that is, it ignores the resistance of friction; but it is on

account of the latter that its superiority is reduced. Figure 9 shows a form of "geared" differential pulley. With this block one man can lift 2000 to 5000 pounds. It will hold the load at any point, and cannot run down.

Winches.—Figures 1 and 2 (*pl.* 109) exhibit derrick winches as applied to single and double poles. They are provided with a safety brake, which prevents the handles from flying back when "let go," and in this case the automatic action of the brake holds the load suspended. The load can only be lowered by turning the crank-handles backward.

Derricks are largely employed for outdoor work, such as building, shipping, etc. They are simple in form and construction, but their convenience and efficiency are less than that of a crane. Derricks are arranged for operation either by hand or by power, the more common form being simply provided with winches (*figs.* 1, 2), as illustrated by the boom derrick in Figure 6.

Windlasses.—The simplest form of construction of the windlass type of transport machines consists of a roller or drum resting in a frame and rotated on pivots by a crank. Around the drum is wound the rope carrying the load or the chain catching the object to be hoisted. A construction of this kind with a vertical drum revolved by hand-spikes is called a "capstan."

Crab.—In its adaptation to cranes and derricks the windlass has many modifications. Increased power is obtained by placing a spur-wheel upon the shaft of the drum and by providing a crank-shaft carrying a spur-pinion engaging with the spur-wheel. A construction of this kind is called a "single-purchase" crab (*pl.* 108, *fig.* 12), which is completed by a brake-plate with brake-lever, a brake-band, which in lowering the load is applied to moderate or to interrupt the motion, and an arrangement for disengaging the crank-shaft. As used upon vessels, it is generally further provided with a cone set externally on an extension of the drum and serving as a friction-clutch in lowering the anchor. For lifting larger loads than is possible with the above apparatus several hand-cranks are applied, and, as a rope of too great thickness would be required, a chain is substituted. This form of machine, whose separate parts can be arranged in various ways, is called a "chain-jack."

Steam-crab.—By the application of a number of hand-cranks a considerable load can be lifted by human power alone, though by employing the power of steam this object can be more effectively attained without an increase of cranks. This form of hoisting-apparatus is shown in Figure 11, in which the two small oscillating engines impart a rotary motion to the winding-shaft from the piston-rods, and is called a "steam-winch" or steam-crab. It is frequently employed for hoisting or lowering the freight of transports. For this purpose two ropes winding in opposite directions are generally placed upon the drum, or two drums are used with ropes winding in the same manner, so that an empty vessel descends while the filled one is lifted; thus there is not only a gain of time, but also a gain

of power, as the weight of the descending empty vessel assists the lifting force. This apparatus is specially adapted for continuous lifting of materials, as, for example, in mining. For the latter purpose the small oscillating engines are replaced either by horizontal or by beam engines of greater power, the chains by wire-ropes, and the drums by the so-called "rope-rolls," which have relatively a large diameter, to prevent the too severe bending and wearing of the wire-ropes. Constructions of this kind are sometimes called "whimseys" (whims, or winding-engines), though this term is more particularly applied to the old atmospheric engines for hoisting coal.

Hoist.—The ordinary rope windlass placed in the attic story of a building and provided with a driving-wheel instead of with cranks, and with an endless rope reaching to the lower story, furnishes the so-called "hoist" as found in storehouses, factories, mills, etc. By reason of the great length of the rope hanging down in front of the building, the drum must have a comparatively greater length. This disadvantage, which is present wherever the rope is very long, can be obviated by the form of construction called the "friction windlass."

Friction Windlass.—The principle of the friction windlass is based upon the frictional resistance of a rope wound several times around a cylinder or drum. This resistance, combined with a slight power acting on the loose end of the rope, holds the load suspended at the other end of the rope, the traction exerted being in equilibrium. The power acting on the loose end of the rope may be the smaller the greater the number of convolutions of the rope around the cylinder. The proportion is such that it can be developed by the hand of a workman or simply by the weight of the loose end of the rope hanging down. As from three to eight turns of the rope suffice for this in ordinary cases, the drum, as also the entire windlass, needs only to be very small if even the rope to be wound up on the one side and unwound on the other is extremely long. The construction of this windlass is, however, complicated by the necessity of having two drums, and hence two drum-shafts, with cog-wheels, etc., for with the use of only one drum the rope in winding up would move in the direction of the axis of the drum, and hence the latter could not be made less in width than that of an ordinary windlass. Friction windlasses of small dimensions are employed in factories and store-houses in connection with tackles, the former being, as a rule, secured to a post or a column, while the tackle is fastened to the ceiling. Of course the load can be lifted only to an inconsiderable height, but the rope, as it must pass through all the blocks of the tackle, has a considerable length.

Friction windlasses of larger dimensions and stronger gearing receive the form shown in Figure 13 (*pl.* 108), which illustrates a machine employed for hoisting the heavy cast-iron girders in the erection of the London Exhibition buildings in 1862. The two fluted friction drums are placed outside the frame, to facilitate the adjustment of the rope. The small cog-wheel engaging the two spur-wheels sits upon

a shaft and is moved by a counter-shaft, which receives its motion from a belt.

A mechanism similar to that in Figure 13 (*pl.* 108) has latterly been adopted in towing ferry-boats on several European rivers. The operating mechanism, known as a *toueur* (towing apparatus), consists of two friction drums, around which is wound a chain whose disengaged parts lie upon the bottom of the channel. The rotation of the windlass by a powerful steam-engine moves the vessel along the chain, which is raised from the bottom of the river and is held firmly to the drums by the counter-weight and its frictional resistance. This arrangement was preceded by one in which the friction windlass was stationed on the bank of the river and drew the vessel by a chain, but instead of hand-cranks it was provided with bars, which were worked by a crew. Such windlasses, called "capstans," are found in Europe even at the present day at rapids and above bridges whose piers, by obstructing the water, cause strong currents.

Differential Windlass.—The so-called "differential windlass" (*pl.* 108, *fig.* 10), a machine of peculiar construction which has been employed by the Chinese for many centuries, has been generally known for a long time. The apparatus is practically the combination on one shaft of two windlasses or drums of different diameters, which counteract each other, thus becoming operative by the difference between the circumference of the two portions. In a modification of the machine the two drums can be mounted on separate shafts, lying in front of or over each other and connected by cog-wheels, but in this case they have the same diameter, the cog-wheels being of different size. In either case, however, a movable pulley (A) is required, which guides the rope to be wound up and from whose block the load is suspended. The principle of its action is as follows:

Each of the two ends of the pendent rope has to carry one-half the load, L, suspended to the pulley-hook, hence $\frac{1}{2}L$. Therefore on the large drum, of radius R, there acts the load momentum $\frac{1}{2}\,Lr$. The momentum of the power acting on the cranks of the length l is, on the contrary, Kl, when by K is understood the combined force of the workmen. It follows, therefore, from the static equation $Kl + \frac{1}{2}\,Lr = \frac{1}{2}\,LR$, that the force required for $K = \frac{R-r}{2l}L$, and the load value $L = \frac{2l}{R-r}K$. Hence it will be seen that with a certain relatively small power—for example, the force of human arms—an enormous load can be lifted, provided the difference ($R - r$) of the drum radius can be made small enough. If this difference becomes naught—that is, if the diameter of both drums is the same—an unlimited load (in a mathematical sense) can be raised; but the height to which it is lifted, being, of course, also equal to naught, the load, notwithstanding the rotation of the drum, remains stationary. The advantage of the simple and inexpensive construction of this windlass as compared with the ordinary chain-jacks, requiring a considerable number of gearings (shafts, wheels, etc.) which render these constructions expen-

sive, is reduced by the fact that to raise loads to any considerable height long ropes and long drums are necessary, which considerably increase the cost of such machines.

Mechanical Combinations.—The gins, tackles, and windlasses above described can be combined in various ways, and thus frequently have the appearance of entirely different machines. Though practically good for special purposes, they are frequently commended as improvements without a due consideration of their mode of action and their degree of effect. Only novices imagine that power is produced by a combination of levers, screws, or wheels. Such a combination, in fact, effects only a transformation; that which remains constant is what is called "mechanical effect" or mechanical performance, and consists of a product of power and lifting height, or power and means, or power and speed.

Power and Speed.—If by the above-mentioned transformation, as effected by the mechanism of a windlass or by any given machine, an increase of power is gained, time is lost, and *vice versa*. If the load moved is one hundred times as great as the power exerted, the duration of the time of transport is also one hundred times as great as it would be if the load and the power were equal. A windlass which with a given power lifts ten times as much of a load as another with the same power, transports the load at one-tenth the speed. This simple proportion between increase of power and loss of speed is, however, modified by the factor consisting of the resistances; as, for example, friction, stiffness of the rope or chain, etc., which are unavoidable with every mechanical contrivance and which cannot be annulled.

Frictional Resistances.—If these frictional resistances did not exist, it would theoretically (independent of the cost of production, convenience of arrangement, erection, easy handling, etc.) be entirely immaterial what form of construction should be employed in a given case. But, these resistances being present, there are, therefore, differences of excellence in the various forms of construction according as to whether their capacity under otherwise equal conditions is more or less decreased by these resistances. The extent of this detriment or the positive effect actually attained remains, therefore, a criterion of excellence as regards the method of construction, and, as the resistances, which may be designated by W, can be considered as an additional load to be overcome or lifted and brought into the calculation, this degree of effect or degree of excellence, if designated by η, can be determined by the symbol $\eta = \frac{L}{L + W}$ to the extent that L indicates the load to be lifted or overcome were the resistances absent.

Comparative Value.—The greater this degree of effect proves to be—that is, the more it approaches, according to the above symbol, to the unit—the better is the machine. Considered from this standpoint, the above-described transport machines may be classified as follows: Differential tackles, the poorest; ordinary tackles, bad; differential windlasses, good; and the ordinary windlasses, the best, provided the gear-wheels are

not too small. This order of succession is, of course, reversed as regards cost of construction. Moreover, it must be considered that in using human power or animal motors in general the development of the power K differs according as the force is applied to drawing a rope, pushing a bar, turning a crank, or pressing a lever (see p. 196); and, finally, in windlasses the advantage is not to be underestimated that some gearings can be disengaged, by which, according to requirement or occurrence, a more favorable relation between lifting the load and consumption of time can be reached.

Cranes.—The use of tackle presupposes a fixed point for its suspension, such, for example, as is furnished by the ceiling-joists of a room, a scaffold, the mast of a vessel, etc. A support is presented to a windlass by a scaffold, a tower, a wall, a well-enclosure, etc. A tackle or windlass with its appurtenances and supporting frame is called a "hoist." If, however, there is no support or fixed point for suspension, and a frame of any desired form or a scaffold-like structure is provided, the combination of the windlass or tackle with such a frame is called a "crane."

The joist secured in the wall of a building, supported by an oblique stay, and carrying on its outer end a tackle or guide-pulley which is connected by a rope to a windlass, forms the transition from a hoist to a crane. The load being drawn up straight, the sphere of action of this transport machine is in a vertical line. By suspending the guide-pulley or tackle from a carriage which can be moved forward and backward upon the joist the sphere of action of such a crane is also in a horizontal plane. This sphere of action can also be obtained by securely fastening the guide-pulley or tackle to an obliquely-set jib which is so pivoted as to admit of its being turned at its foot. The principal features that distinguish the various forms of these scaffold-like structures for hoisting are that a derrick has one leg, a shears two, and a gin three.

Classification.—Cranes are divided into two classes as to their *motions*—namely, *rotary* and *rectilinear*—and into four groups as to their source of *motive power*, as (1) *hand*, when operated by manual power; (2) *power*, when driven by power derived from line shafting; (3) *steam*, *hydraulic*, or *pneumatic*, when driven by an engine attached to the crane and operated by steam, water, or air under pressure carried to the crane by pipes from a fixed source; and (4) *locomotive*, which usually combines both rotary and rectilinear motions, and is operated by steam generated in a boiler on the crane itself. The various types of cranes included under these groups are named as follows: swing, jib, column, pillar, pillar-jib, derrick, walking, locomotive, bridge, tram and travelling cranes, and gantries.

Hand Truck-crane.—Figure 3 (*pl.* 109) shows a light hand truck-crane fitted with spur-gear and drum, and adapted for two speeds. Figure 4 exhibits a jib-crane, which has a rotary motion and a travelling trolley on the jib; the spur-gear mechanism admits of four rates of speed.

Steam-crane.—If the frame of a crane is constructed so as to turn on a vertical axis and a fixed pulley is placed on the outer end of the jib, the

sphere of action is in the line of the convex surface of a cylinder or a segment of it, of which the steam-crane (*pl.* 108, *fig.* 11) is an example. In this Figure the crane-post or stalk is cast in one piece with a cast-iron plate, which is secured to the foundation. Pivoted to the crane-post is the jib with its stay and its drum or barrel, which can be rotated by the small engine. The latter is supplied with steam from a boiler located some distance away by means of the ∩-shaped pipe which passes up the axis of the crane-post.

Derrick-crane.—Figure 7 (*pl.* 109) is an example of what is called a "derrick"- or "free-standing" crane (jib-crane), because the crane-post and jib with its appurtenances are not supported by fixed points, such as a building, etc., but by a separate frame, consisting in this case of obliquely-set wooden stays. This crane is provided with two winding arrangements, one for raising the load and the other for moving the jib.

Travelling Crane.—A crane whose sphere of action is the hollow space of a parallelopiped—that is, in which the load can be transferred to any place in a long workshop, etc.—is illustrated in the form of construction exhibited in Figure 9. This is called a "travelling" crane, and consists of two supports or beams whose ends rest on wheels and upon which a windlass can be moved to and fro, or, as in the present example, where a carriage is drawn backward and forward by an endless chain operated by a stationary steam-windlass, which stands on one end of the crane-frame. The wheels supporting the beams may run upon rails resting on the walls of the building, or, as shown in the Figure, on a specially-constructed frame. In recent forms the movement of the crane, as also that of the windlass, is effected by rope transmission from a motor separated from the crane.

Traversing Crane or Gantry.—Instead of constructing fixed frames for the support of the rails, vertical supports connected by horizontal stays and provided on their lower ends with trucks with the rails placed on the ground can be used. The crane is thus moved upon a railway, by which its sphere of action is considerably increased. In this form it is called a "traversing" crane or "gantry" (*fig.* 8). The construction shown in the Figure consists of iron supports and lattice-like cross-stays. Its movement on the rails is effected by windlasses upon the trucks. For lifting the load it is provided on each side with a winding-gear, and on the cross-beam, at the top, with two carriages, whose backward-and-forward movement is controlled by a windlass on each of the upper ends of the vertical supports, and which can be turned from below by a chain passing down and over a driving-wheel or a crank-wheel.

Railway Portable Steam-crane.—By combining an ordinary stationary crane with a carriage or truck there results a form of construction, called a "portable" crane, which has the same sphere of action as the preceding. By fixing the crane shown in Figure 14 (*pl.* 108) on a carriage and placing upon the crane-frame the steam-boiler, which in the Figure is separate from the crane, there is obtained the portable steam-crane in the form

exhibited in Figure 1 (*pl.* 110). The boiler is so placed as to act as a counter-weight to the loaded jib. If no steam-engine and boiler are employed, the crane being simply operated by hand-power, a separate counter-weight or a clutching arrangement must be provided, to hold the crane upon the rails.

Railway Wrecking-crane.—Figure 5 (*pl.* 109) illustrates a steam railway crane, which consists of a steam-engine and its boiler mounted on a suitable car, and which is employed in railroad wrecks and for construction purposes. Cranes of this type combine the lifting and rotary capacity of the jib-crane with the functions of the travelling crane, but without limitation to the amount of their travel except as to the length of the track available.

Floating Derricks.—An important class of transport machines are the floating derricks employed in rivers and harbors. These huge appliances are capable of raising sunken vessels, of transferring heavy freight to or from docks, of lifting and carrying blocks of granite in engineering works, and of handling heavy bodies whose transfer is not easily effected by other means. They usually consist of a large rectangular float or flat-bottomed boat well braced and stiffened by trusses; sometimes the float is divided into water-tight compartments which can be filled to counterbalance any weight on the opposite side. The float carries a pyramidal frame-work of strong timbers which supports an iron mast called a "king-post," and also the boom, a girder-like construction of sufficient length to give suitable horizontal clearance to the float. The hoisting machinery is placed under the tower, and is controlled by the engineer.

Elevators are of two general classes: (1) those for transferring pulverulent or other loose materials, such as flour, grain, coal, bricks, mortar, etc., from one point to another vertically; and (2) those for raising or lowering goods to or from different floors or levels. To the latter class also belongs the passenger elevator which is provided for the convenience of persons ascending to or descending from the upper floors of hotels and office buildings. Elevators are operated either by hand, steam, hydraulic, or pneumatic power.

Endless-belt Elevators.—The grain-elevator, which was invented by Oliver Evans (see p. 43), is principally employed in flour-mills for the transfer of grain, flour, etc. from the lower to the upper part of the mill-house. It consists of a strong belt carrying a series of metallic buckets or scoops and travelling over a revolving drum at each end. The bucketed belt is enclosed by a casing, usually of wood, in which the buckets pass freely, and as the buckets tip over on the upper drum their contents are discharged into a bin or a chute. The term "conveyer" is also given to such an appliance, but conveyers are more properly those machines which move materials horizontally. (See p. 311.) Ice-, brick-, and mortar-elevators are commonly constructed on the principle of the endless belt, but these are provided with endless chains or linked belts and slats suitably arranged for their different purposes.

Freight Hoists or Lifts.—The simplest type of a hoist for merchandise consists of a winding drum or wooden cylinder for the rope or chain by which the article is lifted, and of a grooved pulley of large diameter over which an endless rope passes for operating the drum and effecting the lift. An improved form is the "double-lift" hoist shown in Figure 2 (*pl.* 110), which has a chain, with a hook on each end, passing over a sheave turned by the hand-rope and wheel. Pulling the hand-rope on either side causes the opposite length of the chain to rise with its load, so that as one hook ascends the other hook descends ready for the next load. A safety-brake holds the load suspended if the hoisting rope be released.

Power Freight-elevators.—The effectiveness of hoisting apparatus was materially increased by the invention of the platform hoist, by which a greater number of articles could be raised at one time. This led to the application of a motive power other than hand-power, and there has resulted the modern warehouse and factory hoist (*fig.* 3), commonly operated by steam. The power elevator consists of a platform (*B*) or a cage suspended from one or more hempen or wire ropes passing over a sheave (*C*); the platform moves in guides or ways which are usually provided with ratchet-plates for engaging the safety-catches in case of breakage of the ropes, and thus preventing the precipitation of the platform. The hatchways or openings in the floors through which the goods are lifted or lowered are in some instances provided with automatically-operated doors, whose mechanism is of various forms, but which are in all cases worked by the elevator itself. Figure 4 exhibits an elevator steam-engine.

Man-engines.—A peculiar form of mechanical hoist, known as a "man-engine," is employed in European mines for raising or lowering workmen. This apparatus was invented early in the present century by Dörrell of Clausthal (Upper Hartz), who made use of two reciprocating pump-rods, to which he fixed small platforms and handles on those parts of the rods that came opposite after each stroke, so that a workman by simply changing his stand from one rod to the other after each stroke would be rapidly lifted to the surface. Figure 5 exhibits a man-engine on this principle, but instead of the pump-rods there are here provided two reciprocating timber rods, 8 inches square, driven by special machinery. The timber rods are furnished with stages or platforms at intervals of 12 feet, the distance travelled by each rod in its up and down stroke. A man stepping on the lower platform of the right-hand rod, for example, is raised 12 feet by the upward movement of the rod, which brings him to the level of the second platform of the left-hand rod, on which he steps, this rod being at its lowest position; the upward movement of the left-hand rod lifts the workman again 12 feet higher, and so by stepping alternately from one rod to the other after each of the reciprocating rods has made its stroke, he is hoisted out of the mine-shaft. The operation of lowering is the converse of the above. At one of the mines in Bohemia the man-engine reaches a depth of 2400 feet, and 3000 men go up and down

it daily in three shifts of eight hours each. In a modified form (*pl.* 110, *fig.* 6) a single rod is used, one set of steps being on the vertically-reciprocating rod, and two sets of landings being fixed on the side of the shaft, one set on each side of the rod. The workmen ascending occupy the set of landings on one side, while those descending occupy the opposite side, thus obviating any confusion in stepping on or off. Thus each step of the rod carries a man in rising, and in descending likewise carries a man, one set of men landing on the platforms on one side, and the other set landing on the opposite side. A string of men thus ascend and descend merely with the labor of stepping on and off as the rod rises and sinks.

Passenger Elevators.—Eligible sites in the business parts of large cities now command almost fabulous prices, in consequence of which their owners are generally erecting taller buildings than formerly, as may be seen in New York, Philadelphia, Chicago, and other business centres of America and of Europe. The available space for offices, etc. is thus made to double its capacity, by the upward extension of the building, in a manner that would have been regarded as useless thirty years ago. The construction of many-storied edifices has been made feasible by the introduction of improved elevators, by which access is afforded to the several floors of a building without the loss of time or the severe exertion required to mount long flights of stairs. The complete system of machinery represented by the modern passenger elevator has, however, been brought to the present state of absolute safety, ease of operation, and thorough efficiency only through a long course of close observation and careful experiment.

Hydraulic Elevator.—Passenger elevators may be operated by steam, gas, or electric engines, or by hydraulic or pneumatic pressure. While the steam elevator is preferred for heavy and continuous duty or for freight purposes, the hydraulic elevator has practically supplanted all others for passenger service. The principle on which it is operated will be understood by the following description and by reference to Figure 1 (*pl.* 111): The carriage is suspended by four or six wire ropes which pass over a sheave fixed above the highest point of the lift, thence under a pulley connected with the piston-rod of the cylinder whose weighted piston nearly counterbalances the weight of the car. One of the ends of the series of wire ropes is fastened at the same level with the overhead sheave, and the other end to the bottom of the car-frame. The cylinder is composed of several cast-iron sections bolted together through their flanged ends, and is vertically set at the lowest point of the elevator well. Leading to the upper part of the cylinder is a supply-pipe, and connected with the bottom of the cylinder is an eduction-pipe, both having suitable gates and valves for the supply and discharge of the water.

The operation of the elevator is as follows: The car being at the bottom of the shaft, the piston is in position at the upper end of the cylinder. The water under pressure, either from the street-main or from a tank on the roof, is admitted above the piston, which is forced down in the cylinder and causes the car to rise, the water in the cylinder under the piston being

permitted to flow out at the bottom at the exact rate at which it enters at the top. In this way the atmospheric pressure, as well as the weight of the column of water above the piston, is utilized to maintain a constant pressure upon the descending piston, which pressure is equal to the hydraulic head from the surface of the water in the upper reservoir to the lower or discharge orifice of the cylinder. The cylinder, however, is always full of water, the escape-valve at the bottom being open only when the piston is falling and the water is coming in at the top; when the car is going down and the piston rising, the bottom escape-valve is closed, the water being simply forced by the rising piston through a circulating-pipe from the top of the cylinder into an opening at the bottom, thus being only transferred from above to below the piston; the car and piston cannot move faster than the gates and valves will allow this flow to take place. The valves can be so fixed that the speed of the car can be exactly regulated independent of the will of the operator in the car. As a further provision against too rapid movement, the passage of the elevator actuates a governor which can be set to regulate the speed as may be desired. If the starting-rope breaks or becomes detached, so that the valves cannot be closed by the operator, the piston can only descend to the lower part of the cylinder, raising the car to the top of the lift, where it will be held safely until the rope can be readjusted or the valves be opened by hand. The most remarkable application of the hydraulic lift is exhibited by the elevators of the Eiffel tower.

Eiffel Tower Elevator.—The great feature of the Paris Exhibition (1889) was the Eiffel tower, whose lofty height looks down on all the tall structures and monuments of the world. Of but little less interest is the means provided for the ascent of the tower, which, owing to the nature of its construction, presented unusual difficulties and rendered it impossible to employ the ordinary "lifts." From the corners of a square whose sides measure about 375 feet spring the four great legs of the tower, which converge in graceful vertical curves and meet at a point some 400 feet above the foundation. At this point is situated the "middle landing" or second floor, whence the tower tapers to its apex. On each side of the square the four legs are connected by arches whose clear spans give architectural beauty to the design; to avoid obstructing these clearances all the means of ascent are placed in the legs and conform to their curves and inclination. The elevators, therefore, are of the character of inclined railways of very steep angle and varying gradients. The original intention was to have an elevator which would rise from the base to the top of the tower, but the construction of the tower was such that a continuous passage or "well" could not be obtained. The difficulty was overcome by placing in each of two diagonally-opposite legs an elevator which ascends to the second floor, whence rise two elevators of the ordinary type to the top. The remaining two diagonal legs are occupied by machines which rise on a straight incline to the first landing midway between the foundation and the middle landing. The two elevators that

presented the greatest difficulties of construction, on account of their ascent at varying inclinations, were of American design, built by American manufacturers, and successfully erected under their supervision.

Figure 3 (*pl.* 111) exhibits a diagonal section through one leg of the tower to the height of the middle landing, and gives a true profile of the track and track-structure on which the car (*fig.* 2) runs. The Figure also shows the hydraulic cylinder, the multiplying gear, the overhead work, the position of counterbalance and track, which lie directly under the main-track structure, and the car approaching the level of the first landing. The track starts at an angle of 54½°, which inclination it keeps for some distance, and then, conforming to the contour of the leg, it passes by a vertical curve to an inclination of 78½°, which is maintained to the end of the run at the middle landing, a distance of 420 feet, or to a vertical height of 395 feet from the foundation.

Figure 2 shows a side elevation of the car-frame, with a section of the car through the aisle and landing projections. The car is double-decked, the arrangement of both compartments being similar to that of an ordinary railway coach—that is, with seats on each side of a central aisle and at right angles to it. The peculiar feature of the car is the aisle floor, which projects in front of both compartments to meet the landing platforms, which are also double, one above the other, at each landing. This aisle floor is constructed like a Venetian shutter, the position of the slats being under the control of the operator by means of a lever. When the car is at the bottom of the tower it is considerably tipped back; the lever being put in the proper slot, each floor-slat is moved into a horizontal position, thus forming a series of steps or a stairway which the passenger descends to enter the car. At the first landing the lever is placed in the middle slot; the slats are then horizontal, but they form an even floor, owing to the position of the car being between the two extremes of inclination, as shown in the Figure. When the car arrives at the top of its ascent it has a tipped-forward position; the lever being again adjusted, the slats when horizontal form a stairway, which the passenger ascends to enter the car. In this way the changes of angle in the car-frame are provided for to effect the landings. The seats, however, are stationary, but the backs and seats are so curved that the sitting passenger experiences no inconvenience from the change of inclination. When he takes his seat in the car at the bottom of the tower he leans well back; upon reaching the top he finds his seat like a straight-backed chair and his body erect.

The motive power is a hydraulic machine whose cylinder (*fig.* 4) is 42 feet long and 38 inches inside diameter, constructed of four 9-foot sections of 2-inch cast-iron pipe jointed at their ends and bolted through their flanges. In addition to the four sections there is a short section at each end where connection is made with the circulating-pipe and water-chest. In this cylinder moves the piston, the machine being so geared that a 1-foot movement of the piston effects a 12-foot movement of the car. Multiplication of speed is produced by the use of auxiliary pulleys, and

the car is raised at the rate of 400 feet per minute. To prevent accidents through any disarrangement or breakage of the operating mechanism, ingenious safety devices are introduced.

The elevators were built to carry fifty passengers per trip, but owing to the inadequacy of the pumping plant furnished by a French concern, the water-pressure was only sufficient to lift forty passengers per trip. Both elevators were intended to run from the ground to the second landing, but it was found that the people would be better distributed to the various stories of the tower if one of the elevators should run during certain hours of the day only between the first and second landings. The tower was open to the public at 9 A. M. and remained open until 10 P. M., or thirteen hours. In this time No. 1 elevator carried 8320 people up and down, and No. 2 elevator carried 11,440, making a total of 19,760 carried each day during the exhibition. The No. 1 elevator made its run of 420¼ feet in one and a half minutes each way, and with the two minutes required at each terminal for loading and unloading, made the round trip in seven minutes, an average of eight trips per hour. No. 2 elevator made its run of 200 feet in forty-five seconds, and with the time required for loading and unloading its passengers, made a round trip in five and one-half minutes, or eleven trips per hour, each elevator carrying its complement of forty persons. This rate of speed was that fixed upon by the commission, but No. 1 elevator under a test made the run from the ground to the second story in forty-five seconds.

2. Transport Machines for Liquids.

As regards their behavior under transportation, there is a similarity between liquids proper—for example, water—and such semi-solids as mortar, and even between them and granular or pulverulent substances, such as sand and flour. The methods employed to lift all these from a lower to a higher level and to carry them from place to place are in some instances practically the same. (See p. 320.) For example, the simple method of filling a bucket with sand or mortar and of carrying it with its contents to the place where the material is needed finds its exact parallel when a pail is used to take water from a stream and to carry it away. The simplest means employed to raise a bucket or a bucket-like vessel and to carry such substances is the hand.

Shadoof.—A development of this is the shadoof (*pl.* 112, *fig.* 1), which is the most ancient water-elevating device. It is found depicted in Egyptian monuments as early as 1432 B. C. Figure 2 is a modern shadoof; the vessel being fastened by a cord to one end of a pole or beam hung upon a horizontal pivot, and the weight being so arranged that it requires a slight exertion to depress the vessel to the level of the water, the weight drawing up both the vessel and its contents to a position where the water may be poured out. A sapling with a thick, heavy butt as a counterpoise for the filled bucket was formerly largely used in rural districts of the United

States, and was known as a "sweep;" this being a corruption of the old word "swape."

The Picotah (*pl.* 112, *fig.* 9) somewhat resembles the shadoof, but it will draw a larger amount of water, the depression being effected by the weight of the operator, who walks along the beam until the vessel is submerged and then goes back to the other end. The picotah is of course intermittent in its action.

Swape.—In most countries where the inhabitants have recourse to wells for water the swape in some form is employed. A somewhat complicated swape is that shown in Figure 6, which dates from A. D. 1568. There are two buckets, one at each end; the vibration of the beam is effected by continuous rotary movement of a cam framed up of wood and turned by a paddle-wheel submerged in the stream in which the buckets dip. Two long rollers fixed to the under side of the beam, against which the working edge of the cam acts, lessen the friction.

Noria.—A number of vessels being fastened to the rim of a large wheel partly submerged in a spring or stream, rotation of the wheel will cause the vessels to be filled and then raised to a position where their contents will discharge into a suitable trough, which will convey the water to a lower level and to a distance. This arrangement, which is exhibited in Figure 3, is called a *noria.*

Bucket-wheel.—For greater depths than would be convenient to reach with a noria the bucket-wheel (*fig.* 7) produces the same result, the vessels being fastened to a chain which passes from a wheel above and is submerged in the water below. The buckets discharge their contents at the highest point into a trough.

The Chain of Pots (*fig.* 10) is another arrangement of the same principle, differing practically only in that the shaft carrying the bucket-wheel is driven by power applied to another wheel upon the same shaft.

The Bascule (*fig.* 5) is a double-ended swape discharging first from one end and then from the other into a trough at its pivot.

Chain-pump.—In all the foregoing arrangements the water or other liquid raised is contained in buckets or bucket-like vessels, each complete in itself and independent of the others. These devices, however, may be arranged in a series comparable to the bucket-conveyer used in flour-mills to carry grain, middlings, flour, etc. But in Figure 11 we find that the bucket proper is wanting, and that the water is drawn up by being forced along before slats or strips attached to a chain or rope passing through an open trough in which the slats fit approximately. This type of machine for raising liquids is analogous to the slat-conveyer used in carrying grain, mortar, coal, etc.

Chain- or Bucket-pump.—A further development of this is the chain-pump or bucket-pump, in which the inclined trough is replaced by a vertical or nearly vertical pipe of circular cross-section, and in which the place of the slats is taken more perfectly by discs or by balls, forming in the latter case what is known as a "paternoster" pump," from the

resemblance of the chain or rope and the balls to a rosary with its beads. In the disc of the chain-pump we find outlined the piston of many of our modern reciprocating-piston pumps.

The Archimedean Screw (*pl.* 112, *fig.* 4) consists of a spiral conduit formed either of a pipe wound about a central drum, or of a cylinder having a spiral partition. The drum or cylinder being inclined and having one end dipping in a source of water, continuous rotation in the direction in which the spiral runs around the axis in coming from above downward drives the water around and upward, so that it is discharged at the upper end of the spiral conduit. In this case the piston which forces the water along in the spiral passage is the water itself. The screw is a continuous scoop.

Pumps.—All the devices above described suffice for raising liquids only comparatively short distances vertically, and for transporting them only short distances laterally by no other means than gravity after they have been raised. Where it is desired to transport liquids very long distances by other means than gravity, there are generally employed machines composed of a pipe-conduit and a mechanism which, while it may or may not raise the liquid from a distance not exceeding a theoretical maximum of about 33 feet, forces it under pressure through the conduit. Such mechanisms for transporting liquids are called "pumps," and consist either of a reciprocating piston working with alternating lengthwise motion in a cylindrical pump-barrel, or of one or more rotating pistons working in a case, these being combined with a pipe system through which the fluid is drawn into and forced out of the pump.

A pump may lift its fluid from a lower level, discharging it at its own level, or may take it from its own level and raise it to a higher, or may do both. Instead of raising it to a higher level, it may do what is the same thing as regards the work done and the method of doing it—namely, it may force it to a considerable lateral distance against the resistance offered by friction, or it may compress it into a vessel against a considerable pressure.

Single-acting Suction Piston-pump.—An ordinary single-acting suction or lifting piston-pump (*pl.* 113, *fig.* 1) has a vertical cylinder or barrel in which there plays air-tight but easily a disc or piston in which is a valve that permits the fluid to pass upward, but not downward. When this barrel is placed in air-tight communication with a source of liquid directly below it at a distance of only a few feet, raising the piston from the bottom of the barrel to the top will form a vacuum, which the liquid below rises to fill. If there be at the bottom of the barrel a valve similar in action to that in the piston, this will permit the liquid to rise in the barrel, but not to flow back. Depression of the piston will cause the liquid to pass through the valve in the piston without rising in the barrel; but on the next upstroke, when the valve in the piston is closed, the piston will raise the water in the barrel and force it out of the top. The pipe through which the water is raised is called the "suction-pipe;" the orifice

through which it is discharged is called the "discharge opening," and is sometimes arranged in spout-like form. The lower valve through which the water is admitted to the pump-barrel below the piston when the piston is raised is called the "suction-valve," and the valve in the piston through which the water passes on the down-stroke is called the "discharge-valve." It is best to have at the bottom of the suction-pipe a strainer to keep out matters which would be apt to clog the valves or destroy the pump; and it is well also to have at or near the foot of the suction-pipe a valve opening in the same direction as the suction-valve of the pump. This is called the "foot-valve" or "check-valve."

Single-acting Suction- and Force-pump.—This suction-pump may be developed into a single-acting suction- and force-pump by closing in the top of the barrel, providing a stuffing-box for the piston-rod, and making the discharge through a pipe connected at the discharging orifice. Instead of having a valve in the piston, either the lifting- or the forcing-pump may have at its base, besides the suction-valve, another which opens away from the barrel, so that on the up-stroke the water rushes into the barrel to fill the vacuum, and on the down-stroke it passes through the outward-opening valve into the open air or into the pipe system. The single-acting forcing-pump which has a valve in its piston will, if the resistance in the pipe-system is greater than the work of lifting the fluid, be harder to work on the up-stroke of the piston than on the down-stroke. Where the piston is solid there will be more work, under the same circumstances, on the down-stroke than on the up-stroke of the piston.

Single-acting Plunger-pump.—Instead of a disc to fit the pump-barrel, there may be, as in Figure 2 (*pl.* 113), a pole or a plunger working in a stuffing-box, and operating by means of its volume rather than by reason of the space through which it passes.

Differential Pump.—A combination of the plunger with the valved piston is shown in Figure 3, which represents the special form used in the Berlin water-works for pumping to the filter the water to be clarified. The suction-pipe, seen in the centre of the Figure, is here by reason of its great size given a form differing from that of the ordinary valved piston. Its valve, like the suction-valve below it, consists of two steps, each of which contains a horizontal annular grating for the support of the rubber "clacks" or valves proper. By the ascent of the double piston the entire quantity of water delivered by the forward and backward motion is sucked, and the quantity of water contained in the annular space formed by the plunger (which is hollow) and the barrel is simultaneously raised, while by the descent of the piston the portion of the mass of the water passing through the valved piston and not finding room in the annular space is lifted. This portion is exactly one-half the entire mass, so that an equal quantity of water is delivered by the ascent and by the descent. The discharge-valve or delivery-valve, seen at the right on the top of the Figure, has several clacks.

Double-acting Pumps.—From the single-acting pump, in which the

water is raised on the upward stroke only and discharged upon the downward stroke only, through the differential pump, in which it is raised upon only the upward stroke and discharged upon both the upward and the downward, there is a natural transition to the double-acting pump, in which the fluid is taken in and discharged upon each stroke. This is effected by providing each end of the barrel with an inlet-valve and also with a discharge-valve, so that while one end is taking in liquid the other is discharging it under pressure. In this case it is generally best to place the barrel horizontally. A good example is shown in Figure 4 (*pl.* 113).

Double-acting-plunger Forcing-pump.—The pole- or plunger-pump is made double-acting by providing it at each end with an inlet- and with a discharge-valve, and by separating the barrel into two portions by an annular partition through which the plunger passes air-tight. Figure 8 shows one of this type.

Valves.—One of the simplest forms of valve is the plain clack or clappet, consisting of a flat piece of leather or of soft rubber somewhat larger than the aperture which it is to cover, and fastened at one side, so that it can readily open and close. It is best to weight the moving part with a disc of metal to ensure its seating promptly and remaining closed when it should be closed. A simpler valve consists of a ball which lies upon a circular aperture which may or may not be countersunk to afford a seat. A suitable cage or other restraining device prevents its being raised too far or carried out of its place. One form of valve in very common use consists of a metal disc which covers a circular aperture, its rising and falling being guided by a central stem or pin. Sometimes it is aided in seating by a spiral spring around its stem. There are numerous other forms and types of valve: many pumps have, instead of one valve for the suction and one for the discharge, several having a united area equal to or greater than that which would be given to a single valve.

The double-seat bell-shaped valve (*pl.* 83, *fig.* 1) is used for very large pumps, and for still larger ones there is employed the step-valve (*pl.* 113, *fig.* 3) with horizontal or obliquely-placed clacks, the number of steps increasing with the size of the pump. The gill-valve of the pump of the East London water-works (*fig.* 6) has nine such steps, and has the enormous diameter of 31 feet.

Air-chamber.—As the discharge of almost any reciprocating pump, and particularly that of one only single-acting, would be very irregular, there is added to reciprocating force-pumps, for the purpose of steadying the flow, what is known as an "air-chamber"—a spherical, cylindrical, or inverted-pear-shaped vessel in connection with the discharge-pipe (generally between the pump-barrel and the delivery-valve), which, by reason of the elasticity of the air within it, acts as a sort of cushion or spring to the pulsating liquid. Draughting-pumps which have a quick piston speed are also supplied with a similar although smaller air-chamber, placed on the suction side and called the "suction-chamber." Both suction- and

discharge-chambers may be seen on several of the pumps shown in the illustrations.

Means of Driving.—Pumps are driven—(1) by hand, catching direct hold of the piston-rod; (2) by hand, through a lever attached to this rod; or (3) by belts or gearing operated by hand, by foot-power, by the wind, or by animal power; they are also (4) attached directly to motors which drive them without the intervention of belts or gears; and (5) in some cases the motor is a part of the pump proper, its piston being a prolongation of the piston of the pump. This fifth class is so important that it will be given special consideration by itself after the others have been briefly reviewed. Examples of nearly every one of these methods are given in the illustrations, reference to which in detail would be unnecessary.

Rope-pump.—The rope-pump is a very crude device, consisting merely of an endless rope hanging in the reservoir and running rapidly over a wheel at the top. The water which clings to the rope by friction and inertia is led off at the top by a suitable conduit.

Cane-pump.—In the cane-pump (*pl.* 113, *fig.* 7) there is a cylinder whose lower end dips below the surface of the reservoir and whose upper end is attached at the discharge point. A foot-valve or check-valve below the water-level admits the liquid when the cylinder is lowered, and prevents its exit when the barrel is raised.

Diaphragm-pump.—In the diaphragm-pump the raising of the water is caused by the motion of a flexible diaphragm attached to a rod, cord, or chain, so that the volume of the chamber, of which this diaphragm forms part of the wall, is caused to change.

Jet-pump.—An example of the jet-pump is shown in the boiler-feeding injector (*pl.* 79, *fig.* 1). In this the flow of the liquid is caused by the impact of another fluid, which may be a vapor, as in the case of the injector, or a permanent gas, as in that of the tromp, where an air-jet is employed, or a liquid itself, as where a jet of water at high pressure draughts and forces a current of other water.

Oscillating Pump.—The oscillating pump corresponds very closely to the motor in which a hinged piston works in a case or chamber which is a sector of a circle. (See p. 260.)

Double or Twin-cylinder Pumps.—The steadiness of discharge of a pumping-machine is greatly increased by having two cylinders with pistons so arranged that one is forcing while the other is discharging. (The double or twin-cylinder pump must not be confused with the duplex pump.) Steadiness of action is still further increased by having three cylinders discharging into a common delivery. In the latter case they are generally driven from a crank-shaft having three cranks 120° apart.

The Duplex Pump.—The term "duplex" is applied to a direct-acting pumping-machine in which there are two pumping-cylinders and two steam-cylinders, each steam-cylinder working the piston of one pump-cylinder, and the valves of each steam-cylinder being driven by the action

of the other side of the machine, whether by the piston-rod of the other half or by steam discharged at a certain point in the stroke of the other; the essential characteristic of the duplex pump being that each half or side of the steam end is driven by the other half or side of the machine. While two pump-cylinders give steady action to a direct-acting pumping-engine, the feature of making the valve-action of one side depend upon the working of the other causes trouble, in that any slowing of one side retards the other, and this again slows the first side, and so on; so that a trifling difference in the tightness of packing or a little air-pocketing in one cylinder may cause each side to make less than the full stroke.

The Hall Duplex Plunger-pump, of which only one of the steam- and water-cylinders is shown in Figure 5 (*pl.* 113), has for a steam-valve (on each side) a plain flat slide, which stands at the left of the stroke, admitting steam to the right of the piston and moving it to the left. When the piston nearly reaches stroke-end and passes by port *A* (port *B* being closed), some of the steam which is moving the main piston passes through port *A* and follows a passage which leads to the steam-chest of the other steam-cylinder, whose slide-valve it shifts. The plunger is a long cylinder fitting air-tight in a short cylinder, which is practically the face of a packing-ring or partition which divides the pump-casing in two crosswise. There are two sets of suction-valves (*e*) and two sets of discharge-valves (*c*), each set acting for one end only. The Figure shows one set of each of the valves open.

Compound Duplex Piston-pump.—Figure 4 shows a duplex pump in which the steam-ends are "compounded;" that is, the exhaust steam of the high-pressure cylinder *A* discharges into the steam-chest *C*, and is expanded in the low-pressure cylinder *B*. There is a short, solid water-piston playing in a long cylinder, above which are all the water-valves *E*, there being two sets of suction-valves on the lower plate and two sets of discharge-valves on the upper plate. In the Figure the steam-valves are in position to let steam in at the right-hand end of the high-pressure cylinder and to drive the piston to the left. The steam in the right-hand end of the high-pressure cylinder acts by expansion only, and the left-hand end exhausts into the steam-chest *C* of the large cylinder. The left-hand end of the large steam-cylinder exhausts into the air or into a condenser.

The Worthington Duplex Pump (*fig.* 8), the best known of its class, moves the steam-valve of each side through purely mechanical means by the piston-rod of the other side. There are many other makes of duplex pumps in which each side mechanically moves the valves of the other.

Figure 1 (*pl.* 114) shows the pumping-engine of the Brooklyn (N. Y.) water-works, and Figure 3 (*pl.* 115) that at Brunswick, Germany. The pump piston-rods are prolongations of the steam-cylinder piston-rods, and the fly-wheel in each case simply steadies the motion.

Centrifugal Pumps include those devices which have a paddle-wheel or vane-wheel rotating in a case (*pl.* 114, *fig.* 2), and which by the repeated rotation of this wheel draws the water in at the centre of the case and throws it by centrifugal action to the periphery of the case, whence it may

be taken up tangentially in any direction. In one of the best-known forms the suction-pipe is branched so that the liquid being pumped enters the chamber from each side, and the casing, which fits snugly to the blades of the wheel, is surrounded by a channel having a circular cross-section which increases in diameter from one part of its circumference until it has made a complete revolution, when it is led off at a tangent. The centrifugal pump requires to be worked at a high speed of rotation, but it is useful for handling large quantities of water which are to be draughted only a short distance and not forced against any great head or pressure. It is well adapted for wrecking purposes, for pumping out dry-docks, etc.

Rotary Pump.—The rotary pump has in its design and construction very much the same principle as is found in a rotary engine (p. 260). In it, by the continuous rotation of one or more winged or toothed pistons in a cylinder or other suitably conforming case, there is formed a partial vacuum, and the water which rushes up to fill this vacuum is swept up and discharged by the rotating wing or wings. There may be one piston which sweeps past the inlet and the discharge opening, or two which are practically gear-wheels with one or more teeth each, these teeth meshing air-tight with each other and with the walls of the chamber or case. Where there are two pistons, instead of there being one wing which sweeps past the inlet and the outlet openings and fits air-tight all around the case there are two; and each during part of the revolution fits the chamber, and during the rest of the revolution fits the other piston.

The Silsby Rotary Pump (*pl.* 115, *fig.* 1) has two rotating pistons, each of which has three long teeth meshing in three depressions in the other, and six shorter teeth similarly meshing. The three long teeth of each fit snugly against the walls of the casing. The suction is into the casing at a point below the line connecting the two shafts, and the discharge is at a point diametrically opposite. Nearly any rotary pump might be used as a rotary motor, and *vice versâ*, although the duty would be low.

The Positive-piston Pump (*fig.* 2) has two rotating rollers, each of which is cylindrical, and one of which has a projecting tooth, while the other has a corresponding depression, so that as they are rotated with their peripheries in contact they mesh precisely in the manner of gear-wheels. The tooth or projection of the larger one closely fits the walls of the cylindrical casing, which is intersected by another in which the toothless piston rotates with a snug fit. The suction is central, passing through the toothed cylinder, in which there are screw-propeller-shaped blades. The water, which is drawn in all the revolutions of the toothed cylinder, passes through an opening in the periphery of the latter into the space between it and the casing, and is discharged at a point in the outer casing about where the two cylindrical casings intersect. External gears insure the perfect meshing of the rotating cylinders. In construction there are two of each of these cylinders on one axis, to steady the running and the discharge.

Artesian-well Pump.—Figure 3 (*pl.* 114) shows in section a vertical bucket-plunger steam-pump for non-flowing artesian wells and for deep-

driven wells. The "working barrel" or pump-end is a casting of hard brass with a pump-bucket and foot-valve, and is screwed on the lower end of the well piping, through which the pump-rod works. The pump-rod connection between the pump-bucket and the upper plunger is of wood or extra-heavy iron pipe. A special arrangement of the steam-valves makes the up-stroke and the down-stroke uniform. The pump-bucket discharges water on the up-stroke, and the upper plunger on the down-stroke.

Oil-line Pump.—Figure 4 (*pl.* 114) shows a direct-acting steam-pump for pumping crude oil through pipe-lines. In this, as the pump-cylinder and its valve-chests are cast in one piece, there are no joints to leak. There is a removable cylinder-lining which can be turned around when one side gets worn by sand or grit. The valve-motion is positive; a horizontal pivoted cam-lever or "rocker-bar," actuated by a projection with a friction-roller on the piston-rod, twists the stem of the chest-piston, which is of the rocking type, and this action uncovers ports by which the main slide-valve is thrown by steam.

Worthington High-duty Pumping-engine.—Plate 116 exhibits a compound condensing pumping-engine, with an attachment which enables it to work at slow speed with as great regularity as though there were a fly-wheel. This attachment consists of two diagonally-placed "compensating" cylinders swinging on trunnions at the end of the pumping-cylinder, each of these auxiliary compensating cylinders having a piston actuated by the reciprocation of a back-rod from the pump-piston, the back-rod having a cross-head moving in guides. The swinging cylinders are filled with the same liquid as that being pumped, and are kept under internal pressure by being connected through their trunnions with an "accumulator" whose ram moves up and down as the plungers of the compensating cylinders move in and out. The accumulator is "differential"—that is, it has below a small cylinder filled with oil or water in which its ram moves, while above it has a much larger cylinder filled with air. On the top of the ram of the accumulator is an enlarged piston-head which fits closely in the air-cylinder, so that the pressure per square inch on the accumulator ram is the pressure of the air in the air-cylinder per square inch, multiplied by the difference between the area of the air-piston and the accumulator ram. The pressure in the air-cylinder is controlled by that in the main delivery-pipe of the pump.

As the pump begins its outward stroke the compensating cylinders are turned to point toward the outer end of the pump, with their plungers at the extreme point of their outward stroke and at an acute angle with the pump-plunger rod, and with the full pressure of the accumulator load pushing them against the advance of the pump-plunger. As the pump-plunger begins its outward stroke each forward movement it makes changes the angle of the two compensating plungers, until at one-half stroke the latter will stand exactly opposite each other and at right angles with the pump-plunger, and then neither retard nor advance the plunger's movement. From this point on the compensating plungers point in the

direction of the pump-plunger's movement and help the latter along, so that steam cut-off may be effected at half stroke or any other point; and by proper arrangement of these parts the plunger movement may be as steady as though there was a fly-wheel.

Gaskill Pumping-engine.—Figure 4 (*pl.* 115) shows the high-duty pumping-engine at Saratoga Springs, New York. It is of the duplex horizontal crank-and-fly-wheel type, having compound condensing-engines with cylinders respectively 21 and 42 inches and pumping-cylinders 20 inches in diameter, the stroke being 36 inches. Its daily working duty for 1889 averaged 107,676,411 foot-pounds of work per hundred pounds of anthracite consumed in the boiler furnaces, and its capacity was 8,156,736 gallons of water in twenty-four hours. It can maintain a water-pressure of one hundred and forty pounds per square inch in the mains.

Fire-engines.—A fire-engine is an apparatus for supplying water in great quantities for extinguishing fire. The name was originally applied to the steam-engine; the first "fire-engines" were steam-engines, and were employed in pumping water from mines. At present the name given means a pumping-engine, and, as the most important types of pumping-engines are operated by steam power, we have the term "fire-engine" again meaning a steam-engine applied to pumping water.

Hand Fire-engines.—The smaller fire-engines (*pl.* 117, *fig.* 1) consist of a tank or box on wheels or runners, bearing a pumping apparatus which draws its supply of water from the tank and forces it through hose attached to the pumps. The box may be filled by means of buckets, though sometimes the pumps draw their water through a suction inlet placed in communication with a hydrant supplying water under pressure, or with a cistern or other source. The pumps of "hand-engines," as these apparatuses are called, are worked by brakes attached to the piston-rods, each brake-rod being worked by as many men as can take hold.

Steam Fire-engines.—A very considerable advance over the hand-engine is the steam fire-engine, which is a self-contained steam-pumping apparatus, the boiler, steam-cylinders, and pumping cylinders being carried in a frame to which is attached suitable running-gear. The smaller engines are drawn by men, the larger by horses. Self-propelling steam fire-engines have been constructed, but they have not been successful.

Figure 2 shows a "first-class" engine, weighing about 8200 pounds and having a pumping capacity of eleven hundred gallons per minute. A vertical boiler supplies steam to two vertical double-acting steam-cylinders, shown to the right of the boiler. The pistons of the steam-cylinders and those of the two pump-cylinders immediately below are on the same rods. The fly-wheel shown in the Figure serves to steady the motion. A suction air-chamber is shown below; the large air-chamber is to the left of the cylinders. The frame, known as "crane-neck," permits the fore-axle to be turned at right angles to the length of the machine. This engine has steam-cylinders 9¾ inches diameter and 8-inch stroke;

pump-cylinders $5\frac{3}{4}$ inches diameter and 8 inches stroke. It will throw from one to four streams, and will project a two-inch stream from 290 to 325 feet horizontally. The peculiar features in this type are the boiler and the pump-valves. The boiler is of the vertical smoke-flue type, with pendent spiral water-tubes; it is shown more clearly in the section on Boilers (*pl.* 76, *fig.* 1). The pump has at each end a number of suction-valves composed of rubber clappets opening inward, and near the centre two ring-shaped discharge-valves, opening outward; these valves have no springs to cause them to seat. The pump-heads are simply cages, and the piston is water-packed.

The Silsby steam fire-engine, shown in Figure 3 (*pl.* 117), has a boiler which, being shown more in detail on Plate 76 of the section on Boilers, needs no description here. The pump, which is of the rotary type, is driven by a rotary engine, and the axes of the pistons or "followers" of the engines are continuous with those of the pumps. A cross-section of the pump is shown on Plate 115 (*fig.* 1). The frame of this engine is "crane-necked," which facilitates turning corners. The axle is "cranked" or bent laterally around the boiler.

3. Transport Machines for Gases.

It is required at times to carry air or other gaseous bodies from one place to another in closed vessels, as for lighting railway-cars, making the hydrogen light, etc. It is also required to empty a closed vessel of air or other gas, or to compress such air or gas at high tension in a closed vessel, or to replace one body of air or gas with another. The means generally employed in all the cases cited except the first consist of a pipe-system connecting the initial and terminal points, and being in communication with a machine for producing rarefaction or compression of the fluid, or both. Rarefaction causes a current of the gas to pass toward the apparatus; compression causes a current of air to pass from the apparatus. Rarefaction may be produced by heat, as in ventilating-shafts and in chimneys, or by friction of moving liquid, as in the tromp; but heat and friction are much less used than those special apparatuses called fans, air-pumps, blowing-engines, and air-compressors, all of which show considerable resemblance to those employed to transport liquids.

Blowing-engines are closely allied to the ordinary piston-pumps for liquids. Figure 1 (*pl.* 118) shows a blowing-engine with a horizontal cylinder connected with the steam-engine. The blowing-cylinder is at the left, the steam-cylinder in the centre, and the crank-shaft and fly-wheel at the right, the steam-piston having a rod projecting through each end of the steam-cylinder. The great weight of the piston renders it desirable that there be a back-rod and an extra cross-head. This engine, which is in the Middlesbrough Iron Works, England, is one of the largest horizontal blowing-engines in the world, the blowing-cylinder being 9 feet in diameter and the steam-cylinder 4 feet, with a stroke of about 9 feet.

The valves of blowing-engines are generally sectional, as may be seen

in Figure 2 (*pl.* 118), this being arranged for a blowing-engine with two cylinders (to the right and left of the Figure respectively). In the centre is shown the blast-pipe for one section. These valves are long cylindrical metal tubes covered with vulcanized rubber. They rest upon rectangular valve-seats, and are covered by straps to limit their motion.

Air-compressors.—For furnishing compressed air to drive rock-drills or motors, or to keep out the water from air-caissons in bridge-building, there are needed compressors delivering air under a tension of several atmospheres; and these differ from blowing-engines more in the proportion of parts than in anything else, requiring of course where steam is used larger steam-cylinders in proportion to the air-cylinders. Air-compressors may be driven by steam, by water-power, by wind-wheels, or by animal power. Those which are steam driven may have a steam-piston upon the same rod as that of the blowing-cylinder, or a steam-cylinder parallel with the air-cylinder, the pistons and their connecting-rods acting upon a common crank-shaft. Where the blowing-cylinder is not directly steam driven, the power may be conveyed by belts or by gears, or, as in the case of water-wheels, directly through a shaft one end of which bears a water-wheel and the other a crank which actuates the connecting-rod of the blast-cylinder piston-rod.

In the air-compressor shown in Figure 9 the air- and steam-cylinders are horizontal and in line. There are an in-take air-cylinder and a compressing air-cylinder, into which the former discharges and which increases the pressure obtained thereby. Both air-cylinders are water-jacketed, to cool the air heated by compression, and there is between the two cylinders an "inter-cooler," a large pipe or receiver filled with thin brass water-pipes, between and among which the air passes. Both the air-discharge valves and the air-inlet valves are of the type used in the Corliss engine, and are operated by the main shaft, instead of the suction-valves being lifted by the external air-pressure and the discharge by the internal tension. The discharge-valves stand still during the period that they are closed with more pressure above than below them.

Rotary Blowing-engines.—Blowing-engines which have rotary pistons are generally called "blowers." They are in most essentials very similar to many rotary engines and rotary pumps for liquids. The Root blower (*figs.* 3, 4) is of this class, as is also the Disston blower.

Fans.—The centrifugal type of blower is the most common. As in many centrifugal pumps, the fans of the blower consist of wheels provided with several straight, curved, or peculiarly-shaped vanes enclosed in casings: by the quick action of the vanes the air in the casings is compressed and whirled into the outlet-pipe, fresh air being sucked in through openings in the centre of the apparatus. Of this type one of the best known is the Sturtevant (*fig.* 6).

Guibal's Ventilator, shown in three-quarter section in Figure 8, as arranged for mine or tunnel ventilation has a diameter of 36 feet, and is operated by a steam-engine whose crank-shaft is a prolongation

of the axis of the wheel. The casing of the air-duct leading from its periphery is of brick. The wheel is of wood, made by fastening joints parallel with the diameter of the casing to the periphery of three octagonal iron hubs, and fixing boards across these joists.

"*Propeller*" *Fans.*—Fans such as the Wing and the Blackman (*pl.* 118, *fig.* 5) do not act upon the centrifugal principle, but work like a screw propeller, drawing the air in at one side of a circular wheel-case and discharging it at the other side. Figure 7 shows a turbine ventilator having several wheels, each being entirely composed of helical paddles. A single wheel has the disadvantage of allowing considerable of the moved fluid to run back through the spaces between the wheel and the inner surface of the casing, so that the compression cannot be increased to a very high degree. To do away with this evil, several such wheels are arranged one after the other, each taking in its suction the air compressed by the one which precedes it. Such a type is called a "multiplying" ventilator.

Exhaust-jet Ventilators.—Upon nearly the same principle as the jet-injector there has been perfected an arrangement by which the end of the blast-pipe of a ventilator or blowing-engine provided with a nozzle terminates in the same axial line as a relatively wide channel. The friction of the air-current in the smaller and central jet draws in air through orifices in the side of the larger channel. In the tromp or water-blowing machine a jet of water is substituted for the jet of air in the last-named jet-exhauster.

In the blast-pipe of a locomotive a jet of steam draws the gases of combustion from the fire-box. In Figure 1 (*pl.* 97) *d* is the smoke-pipe, *c* the smoke-box, and *h* the exhaust-nozzle which receives the steam from the exhaust of the cylinder and ejects it in the direction of the axis of the smoke-pipe *d*. When the engine is not running the same effect may be produced in less degree by a blast-pipe of live steam in the smoke-box, pointing up the stack.

II. TRANSMISSION OF POWER.

1. Appliances for the Transmission of Power.

A complete machine or set of machines is made up of three parts: (1) the prime mover or motor, which receives its motion and force from a natural source, as from animals, water, wind, or steam; (2) transmitting appliances, such as ropes, chains, belts, levers, wheels, tooth-gearing, shafting, or their combinations; and (3) the machine proper which receives the transmitted power. Motors and machines having been fully treated in the preceding pages, the appliances for the transmission of motion and force will alone be considered in this section. We may first observe that the force acting and the object acted upon are separate and distinct, and that while the object of motive force is to drive a machine, the motor can operate it only through connecting arms. These arms (ropes, connecting-rods, mechanical movements, etc.) are properly transmitting machines, the

form and strength of whose mechanism depend on the amount and direction of the motion, and on the force to be conveyed.

Rope Transmission.—Of the various expedients devised by man for the purpose of assisting in his work, the simple process of *pulling* would naturally first be suggested as a means of moving an object. In fact, this process, through the medium of a rope, was one of the earliest methods employed—as, for example, traces, by which animals were attached to sledges and wagons. (See p. 309.) In similar methods of attachment Nature antedates all human inventions, as is shown by the tendons and ligaments, which are a direct means of connection between the motor muscles and the parts of the body to be moved, and which, taken as a whole, effect in an admirable manner all the animal movements, presenting at once the most convincing proof of original and perfected mechanical contrivance for directing and utilizing muscular force.

An ancient means for reaching and drawing distant objects by the direct application of hand-power is shown in Figure 1 (*pl.* 119), which represents the Eastern method of raising water from wells with rope and vessel. Paconius, according to Vitruvius, in order to transport from the quarry a new base for a colossal statue of Apollo in the temple, constructed a machine (*fig.* 2) consisting of two framed-up wheels (*A*, *A*, the diameter of each being about 15 feet), in which he inserted the ends (*C*) of the stone, which was 12 feet long, 8 feet wide, and 6 feet high. From wheel to wheel in their circumferences around the stone were fixed 2-inch spindles (*D*) about 12 inches apart. Around the spindles was wound a rope, to one end of which were attached oxen which, by drawing on the rope and unwinding it, caused the machine to revolve along the surface of the ground; in this manner, by repeated adjustment of the rope, the stone was transported to the site of erection.

Rope-and-Pulley Transmission.—Ancient and mediæval works describe and illustrate various examples of rope-and-pulley transmission employed in raising water and in moving heavy bodies by men and draught animals. (See *pls.* 61, 112.) If we include modern pulley-blocks (tackles) and hand- and power-lifts (*pl.* 108), the varieties will be found to be very numerous.

In Italy in the sixteenth century there was employed a simple but ingenious method of rope transmission by which persons in the upper stories of a building could readily elevate water from a well or cistern at some distance. Figure 3 (*pl.* 119) exhibits this contrivance, which consists of a cord tightly stretched from the ground to a beam projecting from the story to which the water is to be raised. Upon this cord there is a bulb or collar located centrally over the well and acting as a stop. The bucket-rope passes through a ring which slips freely upon the stretched cord, and thence over a fixed pulley in the end of the beam to the hands of the operator. As the bucket and ring glide down the cord, the ring is arrested by the bulb on the stretched cord, but the bucket is lowered to the water in the well. When the bucket is filled it is withdrawn by pulling on the bucket-rope, on which is a knot that comes in

contact with the ring, which then slides up the cord and guides the bucket to the hands of the person operating the rope.

Devices for transmitting power and motion by the use of cords or ropes with pulleys, levers, and other means might be exemplified indefinitely, but those given will serve to illustrate some early inventions which, like all other mechanical methods, have been adapted to the wants of the times in which they have been employed. Many and varied applications will be found in the illustrations which accompany other sections of this volume. In Volume V. (p. 235) are described and illustrated modern rope-transmission systems which may be considered as modifications or extensions of the Roman method shown in Figure 3 (*pl.* 119).

When the power of wind and water was impressed into the service of man, it became necessary to employ some means for transmitting the action of the motor-wheel to the machine. With this need came the invention of gearing, early examples of which will be found illustrated on Plates 3 and 10, and its modern application on Plate 120 and on other plates of this volume.

Belt Transmission.—Belts, by reason of their simplicity and adaptability, are always preferred for the transmission of motion and force, except when the motion is required to be conveyed in exact ratio of the driving and driven speeds. The driving power of belts is due to their frictional adhesion to the faces of the pulleys; under unusual resistances the belts are liable to slip, but their slipping is an advantage, since it prevents injury to the machinery. Flat belts are generally employed; these are mostly of leather and rubber, but many are made of rawhide, canvas, sheet iron, woven wire, and various combinations of these with other materials. Belts for special purposes are round, triangular, trapezoidal, and square, and require specially-grooved wheels.

The plates of this volume illustrate numerous examples of belt-driving, both by primary and by secondary transmission, for the most part by open belts direct from one pulley to another, as is shown in Figure 10 (*pl.* 120), though occasionally by crossed belts, as is shown in Figure 11. Figures 4 and 5 (*pl.* 119) exhibit an arrangement for driving pulleys whose shafts are at right angles, but not in the same plane. When shafts are not at right angles the idler pulley *C* is given a position which will guide the belt properly, keep it in place, and permit motion either way. A single belt may be employed to drive two shafts at right angles, or at any other angle, from the main line of shafting by fixing, in the position shown in Figures 6 and 7, two idler pulleys *B*, *C*. Shafts lying at any angle with one another, and with pulleys on them in almost any position, may be driven with belts by judiciously locating proper-sized and properly-erected idler pulleys.

The driving-power of belts may properly be considered to be derived from friction where low pressures and comparatively large surfaces are involved, and where friction is augmented by heavy oils or applied adhesives, as well as by the tension of the belts. Because of the greatly varied circumstances

under which belts are used, rules for driving-power are not always reliable, yet when certain attainable conditions are fulfilled, belts will transmit forces commensurate with the area of pulley-contact. The use of belting has amply shown that a good rule for general acceptance is that 50 square feet of belt passing any fixed point per minute is the equivalent of one horse-power, or that each inch of width of good leather belting will transmit a force of fifty-five pounds. This may be depended upon for continuous service when the belt is properly surfaced on smooth pulleys running at comparatively high speeds.

Hydraulic Transmission.—Water possesses three properties which eminently fit it for the transmission of force and motion: (1) incompressibility, which qualifies it for positive transmission of motion; (2) pressure, which acting equally in every direction upon equal areas adapts it for promptness in action; and (3) freedom of movement of its particles under pressure, which property gives a frictionless means of carrying force. The principle of hydraulic transmission is illustrated by the simple mechanism shown in Figure 8 (*pl.* 119), which consists of two water-tight cylinders with equal pistons whose rods (a, a') receive and impart the force and motion. If one of the pistons be moved, the other will simultaneously be moved to the same extent and with the same force.

One of the advantages of hydraulic transmission is, that the distance between the actuating and the receiving piston may be adapted to any exigency—that is, the pipes (d, d) may be of any length and either straight or curved, and the cylinders may lie in any plane or at any angle with respect to each other. When it is desired to multiply hydraulically a known liquid pressure—as mechanical force is multiplied by means of levers, screws, and gears—a machine (*fig.* 9) constructed on the principle of the hydraulic press (*pl.* 9, *figs.* 6, 9) meets the requirement. The piston a actuates the larger piston c through the medium of the interposed liquid, the pressure on c being as many times greater than the pressure on a as the area of c exceeds that of a. The motion of each piston, however, is the inverse of these areas, because the area of a multiplied by its movement must be equal to the area of c multiplied by its movement. The effectiveness of the machine is independent of the distance between the two pistons.

Pneumatic Transmission.—The employment of atmospheric air is a feasible and an economical means for telo-dynamic transmission. The engineers of the Mont Cenis tunnel, according to their report of constructive progress in 1863, were engaged at a distance of nearly 2000 metres (6560 feet) from their air-compressors, which operated nine boring-machines with a force of two and one-half horse-power each. The air, under a pressure of six atmospheres, was conducted through an 8-inch tube with a velocity of 3 feet per second. At the working point there was no sensible difference in the pressure, either when the machines were in operation or when they were at rest, and with the mechanical devices employed there was no perceptible loss of power. (See pp. 308, 336.)

Electric Transmission.—A method for the conveyance of power to greater distances than can be effected by either of the preceding systems is presented by the comparatively economical electric transmission, and it is a matter of regret that this important branch of mechanical engineering is not sufficiently developed to admit here of more than a passing notice. The applications of electricity for local power are numerous even at this early date of its installation. (See p. 201; also Vol. V. p. 236.) The cost of transmitting power by wire rope, belting, shafting, hydraulic and pneumatic methods increases in rapid ratio as the distance increases, but it does not so increase with electric transmission, as will be seen from the following interesting table prepared by William Geipel of Edinburgh:

Cost of Plant per Horse-power.

Five Horse-power Transmitted					One Hundred Horse-power Transmitted				
System.	Distance in Yards.				System.	Distance in Yards.			
	110.	1100.	11,000.	22,000		110.	1100.	11,000.	22,000.
Electric . .	$375	$405	$710	$1,050	Electric . .	$160	$175	$205	$435
Hydraulic .	225	485	3050	6,400	Hydraulic .	70	140	820	1550
Pneumatic .	365	1050	5450	10,300	Pneumatic .	130	170	545	960
Wire rope .	37.50	305	3800	6,100	Wire rope .	5.50	45	405	810

2. Mechanical Movements.

Mechanical movements constitute an essential part of transmitting machinery; they may be called the organs of transmission, and they therefore take form in accordance with the direction of the intended motion, and are proportioned to meet the demands of the forces which they are devised to transmit. They may be either simple or complex. When a body or any piece of mechanism moves in a straight line it has a *rectilinear* motion; when it moves in a curved line, a *curvilinear* motion. When a body moves constantly in the same direction it has a *continuous* motion; if it move backward and forward it has a *reciprocating* motion. There are *reciprocating-rectilinear* motions as well as *reciprocating-curvilinear* motions. If a body move without variation over equal spaces in equal intervals of time, it has a *uniform* motion; if it move over unequal spaces in equal intervals of time, it has a *variable* motion.

While it is certain that no machine can be constructed without employing mechanical movements or devices in one shape or another, it is demonstrable that no power is gained by their use, in whatever way they may be combined or operated, as the force that is applied at one point can only be exerted at some other point, and this *force* is always diminished by friction and other incidental causes. The action of force in a machine at equilibrium, considered without reference to frictions and the weight of the machine itself, may be thus formulated: The power multiplied by the distance through which it moves in a vertical direction is equal to the weight multiplied by the distance through which it moves in a vertical

direction. This is called the "golden rule" of mechanics. The power performance of every machine may be reduced to the expression: "What is gained in power is lost in speed;" or, conversely: Whatever is gained in the rapidity of execution is compensated by the necessity of exerting additional force. The function of mechanism is to receive, concentrate, diffuse, and apply power to overcome resistance. The combinations of mechanism are numberless, but the primary elements are only two—namely, the *lever* and the *inclined plane.* By the lever, power is transmitted by circular or angular action—that is, by action about an axis; by the inclined plane, power is transmitted by rectilinear as well as by circular action. The principle of the lever is the basis of the pulley and of the wheel and axle; that of the inclined plane is the basis of the wedge and of the screw.

Mechanical movements, whether simple or complex, must rest or move upon fixed bases or a framework shaped and adapted to their needs. A train of mechanism must be so mounted that when the receiver or first part is moved the other pieces, to which the receiver is connected, must be constrained to move in the manner determined by their construction and by the mode of their connection. There are many hundreds of mechanical movements employed in the construction of machines, but as it does not accord with the plan of this volume to present an exhaustive treatise in this department, we shall confine ourselves to the description of the few well-known forms illustrated on Plate 120.

Levers.—The simplest mechanical element for giving movement and gaining advantage is the prying-lever, or "lever of the first kind," which is shown in Figure 1. The point *A* is placed beneath the object to be raised, the heel resting upon a fixed piece (*C*) called the "fulcrum," and the power is applied to the longer projecting end *B*. With this kind of lever the weight to be raised moves in a direction opposite to that of the power. In Figure 2 is shown the lifting-lever, or "lever of the second kind," whose action is the same as that of the prying-lever, but the power moves in the same direction as the weight. In the "lever of the third kind" (*fig.* 3), the power also moves in the same direction as the weight, but it acts at a disadvantage, as the power is applied nearer the fulcrum, which is at the end of the lever and must be greater than the weight moved. In this method of application Nature antedates man's contrivances, since his limbs are moved by muscular force applied in this way.

Figure 6 shows a combination of a lever and links, such as are used in what is called a "toggle-press." Hand-power is applied to the long arm of the bent lever, which has a wide range of motion; the short arm is connected by a link to the "toggle," which is composed of two links end-on. The upper end of the upper link works on a fixed pin, and the lower end of the lower link works on a pin adapted to the sliding part, which moves toward the object to be pressed as the lever is drawn down and the toggle is straightened. Great advantage is gained by this simple contrivance, the principle involved being a rapid increase of ratio between the distance

through which the sliding-piece is moved by the power applied and the object acted upon.

Figure 7 (*pl.* 120) shows a bell-crank or bent-lever devised for changing the direction of motion. The rod to the right in the Figure, moving vertically, transmits its motion to a connecting-rod which moves horizontally, and through the medium of the crank rotary motion is produced by the vertical reciprocating action of the rod.

Figure 4 exhibits an equal-ended beam, such as is employed for weighing-balances, and, in a larger way, as the walking-beam of a steam-engine (see *pl.* 82), the opposite ends having equal motion simultaneously, but in a reverse direction. The forms of levers as well as the purposes to which they are applied are multitudinous.

Figure 5 *a*, *b* shows the relation an inclined plane bears to the screw. If a triangular piece of paper be wound around a cylinder, the inclined edge of the paper will mark a true spiral, as is shown in Figure 5 *a*. The screw shown in Figure 5 *b* may be regarded as a vise-screw, which is urged by the lever passing through its head. The great mechanical force exerted by the screw is due to the small distance between the threads, which determine the advance of the screw at each revolution, and to the extreme length of lever, which is applied in turning the screw.

Pulleys.—Figure 8 shows a single fixed pulley (*A*) and a single movable pulley in combination with a fixed pulley (*B*). In the first the power and weight are equal, both moving equal distances, but in opposite directions. In the second the power required is but half the weight lifted, but must pass through twice the distance in an opposite direction. The weight hangs upon the running pulley which rests in the fold of the cord, one end of which is fast while other parts lie in the groove of the fixed pulley. As the weight is equally divided between the two parts of the cord, it is plain that a force equal to only half the weight will be necessary to lift it, and it is also plain that the power must move through a space twice that passed through by the weight, since it must take up both parts of the supporting cord. Figure 9 shows the common balance-pulley and buckets for raising water, the empty bucket being pulled down to assist in raising the full one.

An extension of the principle of the pulley-block is shown in Figure 13, known as White's system of concentric pulleys. It is a very ingenious combination, but is attended with more friction on the rope than the above forms, owing to the difficulty of preserving the working-pitch line of the ropes in the grooves in a proper proportion.

On Plate 123 (*fig.* 4) are shown the spring-box and conical wheel called a "fusee" which is designed to equalize the varying power of the main-spring of a watch or clock by winding the chain in a conical groove adapted to the tension of the spring. (See p. 362.)

Figure 10 (*pl.* 108) exhibits the differential or Chinese windlass, in which both ends of the rope are fastened to the barrel, there being one runner pulley connected to the weight to be lifted, while the strips of the rope wind on different-sized parts of the barrel, the effect being that as at

the same time that one strip is wound on one part of the barrel the other strip is unwound from the other part, and as the circumferences of the ends of the barrels are different, the rope must either be paid out or drawn up (according to the direction in which the drum is turned) a distance equal to the difference of the circumferences of the barrels multiplied by the number of turns made by the drum. The movement of the pulley to which the weight is attached, in every revolution of the windlass, is equal to half the difference between the larger and smaller circumferences, and its power must be rated accordingly.

In all the mechanical elements above described the motion is reciprocating, is limited to the length of the lever and of the ropes and chains, and may be successively repeated. In Figures 10 to 12 (*pl.* 120), which show an endless cord passing over two pulleys, the motion is continuous (running either way), first in the same direction (*fig.* 10), secondly in reversed directions (*fig.* 11), the axes of the pulleys being in both cases parallel to each other. In Figure 12 the axes may lie at any angle with respect to each other, but not in the same plane, and the motion is continuous in both. In these examples the number of revolutions may be increased or diminished according to the circumferences of the pulleys enfolded by the cord.

Figure 14 exhibits the common crank, a simple method of producing rotary motion by hand; while Figure 15 shows the means of producing rotary motion through a treadle by the action of the foot. By the device shown in Figure 16 rotary motion is imparted by one going-wheel to another wheel of the same or of different size by the frictional contact of truly-formed cylindrical surfaces whose axes are parallel, and whose surfaces are held together by a certain constant pressure; the material in contact may be of wood, rubber, leather, rawhide, metal, or any combination of these materials.

Liability to slipping is inseparable from all devices which drive by contact. To overcome slipping and to make the imparting of the motion sure and positively proportional to the circumference of the wheels, there are formed upon their peripheries teeth which, being evenly spaced, engage with one another and impart motion and force without loss of velocity. A pair of engaged spur-wheels with external teeth are shown in Figure 17, their shafts turning in opposite directions. In Figure 18 the larger wheel has teeth formed on the inner circumference, while the smaller wheel has the teeth on the outer circumference. In this example the shafts turn in the same direction at speeds inversely proportionate to their diameters, and the wheels have more teeth in contact at all times than have those in Figure 16. In both cases the motions of the shafts are uniformly circular.

If an irregular motion be required, as when during half the revolution the outgoing movement must be slow and the incoming movement rapid, an arrangement of elliptical cog-wheels (*fig.* 19) meets this requirement when the shafts are placed in the foci of their ellipses, but the pulsations are doubled per revolution when their shafts are placed in their centres as

shown. The cog-wheels in Figure 20, called "rectangular gears," produce four waves of motion during each revolution. All gears not truly circular—and their forms are numerous—are devised only for special purposes.

In all the given examples of gears the shafts of each pair are parallel. When it becomes necessary to drive shafts that lie in the same plane but are at an angle with each other, conical cog-wheels are employed in which all the working lines on the faces of the teeth converge to one common centre, which is coincident with that through which pass the axes of the shafts. Figure 21 (*pl.* 120) shows gears of this sort, which are called "mitre-wheels" when both wheels are alike and upon shafts that are at right angles, and "bevel-wheels" when of different diameters, whatever the inclination of their shafts. The movement shown in Figure 22, to which the name of "perpetual screw" has been given, consists simply of an ordinary screw that engages with a spur-wheel having teeth set at an angle across its face and conforming somewhat to the screw-thread. The screw in this case may be considered as a cog-wheel of one tooth, which, instead of being parallel with the axis of the wheel, is wound spirally around the screw-hub, and as a consequence the wheel which it drives is advanced only one tooth at each revolution of the screw. The screw may also be applied to propel a rack, as is shown in Figure 23, which is the most ancient form (as early as the fourth century) in which the screw was employed. A superb modern application is that devised by William Sellers & Co., in which a screw upon the end of a shaft lying at an angle with the moving bed of a planer drives the bed back and forth. (See p. 121.) The rack and pinion is shown in Figure 24, in this example having *skew* teeth. In both these examples the motion cannot be continuous, as in Figure 22, since the length of the rack determines the movement.

Figures 25 and 26 represent ratchet-and-pawl contrivances; the first with lever and pawls for actuating the wheel in a step-by-step intermittent way, and the second with several forms of "stops" or catches for holding the motion obtained. In Figure 27 the device is given a linkage connection, by which the pawl is automatically raised from the tooth space on the wheel and is lowered into another space by the same motion of the lever that rotates the wheel.

Gears to which the name of "differential" has been given are shown in Figures 28 and 29, the first representing one broad-face spur-pinion gearing into two narrow-face spur-wheels having a different number of teeth—for example, one tooth less in one wheel than in the other. It is evident that when the pinion counts all the teeth of one spur-wheel it will lack or will exceed one tooth of the other wheel; hence the two spur-wheels have a differential movement. The same result takes place with the movement shown in the second example: the pinion turns freely upon a hub on the shaft, gearing alike into two internally-toothed rings, one of which has one tooth less than the other. If we fix one ring from turning and permit

the other to turn freely upon the common axis, we shall find that when the pinion matches the teeth all around one ring, the other ring will have an advance or a retrograde movement of one tooth per revolution.

A differential movement whose principle is employed in the construction of counting apparatus is shown in Figure 30 (*pl.* 120). Two concave-cut wheels are so arranged that a screw will fit into the teeth of both wheels at the same time. If, for example, one of the wheels has one hundred teeth and the other wheel has one hundred and one teeth, then for each hundred revolutions of the screw the hundred-toothed wheel will make one revolution, and the other wheel will lack one degree or one-hundredth of a complete revolution. This differential rotation of the wheels is made visible by fastening to the hub of one wheel and to the axis of the other a hand or pointer; these at starting are so set that the two pointers shall coincide at the zero point: upon the completion of the rotation of the wheels it will be seen that the pointer of one wheel is one division or a degree in advance of the other.

Figure 31 is an application of internal or "epicycloidal" gear to pulley-blocks or hoisting machines. The toothed ring is connected with the mechanism to be moved; the propelling spur-toothed wheel within is centred upon an eccentric-hub on the shaft, but is prevented from revolving by the arm whose slotted extremity slides upon a fixed pin. One revolution of the eccentric makes the inner wheel interlock its teeth all around with those of the ring, but as the ring has a greater diameter, and consequently more teeth, it lacks the difference of circumferences of completing a revolution. In Figure 32 is shown a rotary screen in which a large bevel-toothed ring is secured to the floor; the spindle of the screen rests and revolves in a ball-joint; about midway on the spindle is a bevel-pinion which gears into the teeth of the fixed ring. Turning the spindle imparts not only a rotary motion to the pan or screen, but also a rocking motion.

To obtain an indefinite increase of the power of the screw, without diminishing the strength of the thread, two screws having different pitches (as shown in *fig.* 33) were proposed by Dr. Hunter, whose contrivance is known as the "differential screw." While the working point is urged forward by the screw that has the greater thread, it is drawn back by the screw that has the lesser thread, so that during each revolution the screw, instead of being advanced through a space equal to the pitch of either of the threads, moves through a space equal to their difference.

For irregular and intermittent motions devices called "cams" are employed. A cam is a projecting part of a wheel or other moving piece, so shaped as to give the desired motion to a piece sliding against or rolling upon it. Figure 34 shows a side-face cam for imparting one movement at each revolution of the cam; Figure 35 is a cam for giving a succession of lifts and drops to a piece moving vertically, as a stamp; and Figure 36 gives the heart-shaped cam, which imparts a uniform outgoing and incoming motion to the rod jointed to the lever. Figure 37 is similar to Figure 34, but is double-acting; its opposite face is

for making the return motion certain. Figure 38 illustrates a more complicated arrangement of cam, lever, and rod. Two cams operate two similar levers and rod-connections. The cams are so shaped that during three-fifths of their revolution the levers will be moved uniformly upward, and of course each will descend during two-fifths of a revolution. If now each rod be attached to a pump-bucket with a valve lifting upward, both rods working in the same pipe, and if the cams be set with their like motions opposite each other, there will result the working principle of the "equable pump" invented by Mr. White prior to 1822, and reinvented many times since.

Figure 39 (*pl.* 120) may be classed among cam movements; it represents the barrel-motion of musical instruments, looms, and the like, in which the barrel is provided with pins or staples for lifting their respective levers or parts to which either instantaneous or prolonged motion is to be given.

Mechanical devices are usually employed for modifying and directing motión, but are also employed for reducing and stopping motion by the application of brakes and friction-pieces. The common brake-block, forced against a wheel by a lever, is shown in Figure 40; in Figure 41 there is presented a more elaborate device, which consists of a flexible band faced with separated blocks (so as to increase the area of contact and insure its uniformity), which are forced to embrace the wheel by a lever that has a counterweight adapted to relieve the embrace of the band when the pressure is removed. Figure 43 presents an ingenious device, called a "rope-brake," which checks or stops a running rope by the grip of the brake-jaws when the angular distance of their centres becomes less, as it does when the lever end is pressed down. Friction surfaces may be multiplied in many ways. In the case of a brake acting as a check to rectilineal moving pieces, compound plates with intermediate friction surfaces are used, as represented in Figure 42. The friction surfaces are all forced into close contact at once by right- and left-hand screw-grip levers operated by a hand-crank or by other means. In various kinds of revolving mechanism driven by a cord, a weight, or a spring, the speed may be reduced, and regulated within certain limits, by the fan-brake (*fig.* 44), which may be run in the open air or in a liquid enclosed in a box.

The adjustable friction-gearing (*fig.* 45) of J. W. Howlett illustrates one of the many uses to which rubber has been effectively applied. The upper wheel *A* is composed of a V-edged rubber disc clamped between two metallic plates. By screwing up the nut *B*, which holds the parts together, the rubber disc is made to expand radially and to press more tightly in the groove of the larger wheel, thereby obtaining greater traction.

Figure 46, called an "ellipsograph," is more of an instrument than a mechanical movement. The traverse-bar carries two studs which slide in the grooves of the cross-shaped piece. By turning the traverse-bar an attached pencil is made to describe an ellipse by the combined rectilineal motions of the studs in the grooves.

Figure 47 exhibits the so-called "flexible angle-coupling." The ends of

a spiral spring are fastened to two shafts which may lie at any angle with each other; the flexibility of the spiral maintains the connection between the two shafts and transmits the rotations of one to the other. A wire rope connected in a similar manner accomplishes the same purpose.

To limit the number of revolutions of a wheel, as in winding a watch whose mainspring would be endangered by overwinding, is the purpose of the "Geneva stop" shown in Figure 48 (*pl.* 120). It consists of a wheel (*A*) with a single slightly-projecting tooth, and of a star-wheel (*B*) with four concave teeth and one convex tooth (*a*, *b*) called the "stop." The operation of the movement is as follows: At each revolution of the wheel *A* its tooth engages one of the concave teeth of the wheel *B*, enters the tooth-space, and moves the wheel *B* to the extent of one tooth. When the convex tooth or stop *a*, *b* comes in contact with the tooth of wheel *A*, the latter is prevented from turning any farther by reason of the convexity of the stop, which cannot pass the projecting tooth. The uncoiling of the mainspring reverses the movement of the wheels until the tooth *a*, *b* comes into position on the opposite side, when, by rewinding the spring, the above-described operation is repeated.

To the mechanical movement shown in Figure 49 has been given the name "lazy tongs," which is a connected system of cross-links jointed at their crossings and angles. When the links are alike, the four-sided spaces are all uniformly enlarged or diminished by the rectilinear motion of the rod. Whatever motion is given to the link to the right (which is fixed at its junction with the next link) by the rod at its salient centre, will give a similar but much greater motion to the link and rod at the left.

A simple contrivance known as the "governor," by which advantage is taken of the ever-present gravitation and centrifugal force acting through a pair of weights and jointed levers, is shown in Figure 50. The adaptation to the steam-engine of this expedient, which was long in use for regulating the speed of millwork and other machinery, is due to the ingenuity of Watt. It consists of two heavy balls (*B*, *B*) attached to the extremities of the rods *F*, *F*, which are jointed at *E*, and pass through a mortise in the vertical stem *D*, *D'*. The upper ends of the rods *F*, *F* are connected by links to a sliding collar (*D*) in which fits the horizontal lever *I*, *G*, *K*. This lever is jointed to a fulcrum-pillar at *G*, and to a link (*K*, *I*) which operates a valve (*V*) in the steam-pipe that supplies the engine. The motions can be easily traced through the various parts—increase of velocity throws the balls farther from the centre of motion, draws down the collar, raises the lever at *I*, and partly closes the valve. A reduction of velocity reverses these motions and produces an opposite effect. The property which renders this instrument so well adapted to its purpose is, that there is but one velocity at which the balls can remain in equilibrium. It governs the speed of the engine because the slightest change in the velocity causes a considerable movement of the steam-admission valve.

(J. H. C.)

PART III.

MACHINES FOR MEASUREMENT

AND

SPECIAL APPLIANCES.

PART III.

MACHINES FOR MEASUREMENT AND SPECIAL APPLIANCES.

A. MACHINES FOR MEASUREMENT.

IN a general sense the term "measure" is applied to that by which anything is compared in respect of quantity. Thus we have measures of extension, of weight, of time, of force, of resistance of temperature, etc.—in short, of everything of which greater or less can be predicated; and it frequently happens that the unit of measure is not taken in the thing or property which is the immediate subject of consideration, but in something else which depends on it or is proportioned to it. Angular space, for example, is measured by an arc of a circle; time, by the rotation of the earth about its axis or its revolution about the sun; force, by the quantity of motion it impresses on a body; degrees of heat, by the expansion of metals or other substances; muscular strength, by the resistance of springs, etc.

Classification.—Measuring machines may be classified in two general divisions—namely, (1) those for measuring material substances, and (2) immaterial quantities. Machines for the measurement of material substances may be arranged in three classes: (1) those for solids, (2) those for liquids, and (3) those for gases. The appliances for the measurement of immaterial quantities may likewise be divided into three classes—namely, those for the measurement (1) of time, (2) of space, and (3) of motion or force.

1. Measurement of Solids.

The measurement of solids may be determined by two methods—namely, (1) by linear measure and (2) by gravity. As the appliances for the first method of measurement consist for the most part of simple instruments—for example, the foot-rule, tape-line, etc.—we shall confine the following treatment to those machines whose measurement is by gravity or weight. Weight in experimental philosophy and in commerce is the measure of the force by which any body or a given portion of any substance gravitates to the earth. The process by which this measure is obtained is called "weighing," and when required, as in many philosophical experiments, to be performed with great accuracy, is a tedious and delicate operation. The measurement of weight, like that of exten-

sion, consists in the comparison of the object to be measured with some conventional standard. But it is impracticable to fix such a standard by any written law or by oral description, for it is impossible to communicate by words, without reference to a perceptible object, any adequate idea of a *pound*-weight or of a *foot*. Standards of linear measure not accurately defined, but having an average value sufficiently well known for the rude purposes of mankind in the early stages of civilization, were furnished by the different parts of the human body, from which are derived the foot, cubit, span, etc. (See p. 382.) A method of comparing the weights of bodies does not suggest itself so readily to the mind as does a method of comparing their linear dimension. A balance is necessary, whose construction requires some degree of mechanical knowledge; hence the art of weighing, though of great antiquity, was probably practised at a later period and in a less accurate manner than was that of measuring. There have also been much less definiteness and a much greater variety in standards of weight than in those of measure, as will readily be understood if we consider the origin and import of such terms as stone, lead, etc. The term "pound" (*pondus*) implies weight only indefinitely. As a unit of weight, the "grain" (*granum*), taken from the grains or corns of wheat, was perhaps the only denomination of weight that would universally convey anything like a precise idea. The discovery of specific gravity by Archimedes led to many important applications of measures of gravity.

Weighing Machines, or scales, measures, and weights, have in some form been in use from time immemorial. Pliny ascribes their invention to the Romans, but they were known and employed many centuries anterior to Roman history. In very ancient Egyptian paintings the merchant is seen with his scales carefully weighing his wares, and in China scales have been in use from the dawn of history.

Balances.—The original form of weighing-scales was probably a bar suspended at its centre, with a board or a shell suspended from each end, one to contain the weight and the other the article to be weighed. In early times, before the coinage of money, the precious metals were weighed out; the duty of weighing being regulated by the municipality and attended to by public weighers, as is seen in the Egyptian monuments and as is recorded in classic literature. Figure 1 (*pl.* 121) is from an ancient Egyptian papyrus in the British Museum, representing the "Ritual of the Dead."

The Biblical balance was similar to that of the Egyptians; the ends were of equal length, and the beam was suspended at its mid-length. When Abraham (1860 B. C.) bought from Ephron the Hittite the field containing the cave (Gen. xxiii. 13–16), he "weighed to Ephron . . . . four hundred shekels of silver current money with the merchant." The sale was made in the presence of witnesses, and is believed to be the earliest transfer of land of which a record survives.

The balance of Archimedes was a beam with a bowl suspended from a fixed point at each end. On one arm of the beam, which was graduated from the fulcrum to the point of suspension of one of the bowls, was a

movable weight; by adjustment on the arm the weight made a counterpoise equal to the difference between the weights in the respective bowls.

The *libra* or balance of the Romans, in its simplest form, consisted of a mere beam with a pair of scales,[1] one at each end, and a ring or short chain placed in the centre of the beam to serve as a handle by which to poise it. In some cases the beam was furnished with an index or tongue working in an eye to mark the variations in weight; and sometimes the beam was divided into fractional parts with a weight attached to it, by means of which the difference in weight between two objects could be decided without the necessity of having recourse to a number of fractional weights for the purpose.

Balances for delicate operations, such as those used in assaying and in chemical manipulation, are made with extreme care. The sensitiveness of a balance so constructed may be carried to an almost inconceivable extent. Analytical balances are usually made to carry one thousand grains in each pan, and to "turn" with the $\frac{1}{1000}$ part of a grain. There are in the English mint several large balances calculated to weigh from 1000 to 5000 ounces Troy, some of which will turn with one-tenth of a grain when loaded with 1000 ounces in each scale, or with $\frac{1}{9000000}$ part of the weight.

Steelyard.—The steelyard is a much later apparatus than the balance, and is supposed to be an invention of the Chinese. The frequent Biblical references to false and unequal balances show that the lever-balance on the principle of the steelyard was unknown. The Roman *staterae* exhibited in Figure 2 (*pl.* 121), which are from originals discovered at Pompeii, are the same in principle as the modern steelyard and weigher's beam. The *statera* consists of the yard (*scapus*), which is divided into fractional parts (*puncta*) and suspended from above by a hook or a chain. The short end of the yard is furnished with a hook, and sometimes with a scale, for affixing or for holding the objects to be weighed, the longest end of the yard being provided with a sliding weight.

The lever of unequal lengths from the fulcrum or point of suspension affords a convenient mode for determining weights of various objects with but a single weight, the object being suspended from the end of the short arm, while the "bob" is shifted along the graduated longer arm until it forms an exact counterpoise. This is the modern steelyard, which was probably so called in England from its material and former length. The Merchants of the Steelyard were a company of foreigners, chiefly Flemish and Germans, in London (1252), who were long the only exporters of the staple commodities of England.

The Lever-scale on the principle of the steelyard has for many years been used in the United States for all purposes, from that of the letter-scale (*fig.* 6), weighing half ounces, to that of the weigh-lock scales, whose weighing capacity is more than 1,000,000 pounds.

[1] The term "scale" originally designated the pan or balance, but the name is now used for the entire apparatus.

Platform Lever-scales are those on which may be placed the object to be weighed. They have numerous forms and uses by which their construction is determined and their names designated. There are, for example, counter platform-scales (*pl.* 121, *fig.* 7) of a comparatively small size; warehouse scales (*fig.* 8) which are adapted for weighing boxes, barrels, sacks, and large packages, and which can be moved about the floor; also stock and hay scales (*fig.* 13), still larger in form, which are for weighing cattle or for weighing a wagon and its load. The principle of an ordinary platform-scale is readily understood: the graduated knife-edge beam is suitably supported at its fulcrum end, which is connected by a rod to the pivoted levers beneath the platform, and the outer end of the beam rests in a depending arm, so that the beam may be maintained in horizontal position and its vibration checked during the process of weighing. At each corner of the loose platform there is a downward-projecting steel-faced plate, which rests on the knife-edge of the levers, whose free ends are arrested in their downward movement by means of loops. From this description it will be seen that a package placed on the platform will depress the levers, which in turn bear on the connecting-rod attached to the fulcrum end of the beam. If now the weight or poise is slid along the beam until there is a true balance of the beam end, the point on the graduation of the beam at which this balance is effected will indicate the weight of the package. Connected to the outer end of the beam by means of a short rod is the suspended counterpoise, which serves also for increasing the weighing capacity of the machine by supporting slotted weights placed thereon.

Various kinds of weighing scales in common use are illustrated in Figures 3 to 15. Figure 5 represents a single-beam market-scale with sliding poise; Figure 7 is a grocer's simple lever-scale; Figure 4 is a compound-lever platform-scale for stores or for domestic purposes; Figure 3 is an even balance with weights, weighing from half ounces to six pounds; and Figure 9 is a hopper-scale for weighing grain at elevators, the hopper having a capacity of one thousand bushels. The grain is transferred from the railway car or from transports by means of bucket-elevators to the top of the elevator building and discharged into the scale hopper. A slide in the bottom of the scale hopper admits of the contents of the box, after being weighed, being discharged into the grain-bins beneath. With such scales is used the combination beam shown in Figure 11, which consists of a series of graduated beams adapted for weighing different kinds of grain—oats, wheat, etc. Figure 14 exhibits a coal-dealer's scale, which, for determining the gross weight and the tare, frequently has a compound beam similar in form to the compound beam for hay-scales shown in Figure 12, the upper beam of which records the weight in hundreds and thousands, the fractional parts of the weight being recorded on the lower beam. The stock scale (*fig.* 13) and railroad-track scale (*fig.* 15) are modifications of the coal-dealer's scale above described. Suspended scales are represented by the abattoir scale in Figure 10, which is designed for weighing dressed beef (one quarter or more at a time), dead hogs, hogs-

heads of sugar, coal in buckets, etc., which are handled on a suspended track, a section of the track being cut out and hung on the scale levers which are placed above it. The goods are weighed as they pass over the track suspended to small carriages or wheels, as seen in the illustration. These scales are extensively employed in large refrigerators, slaughter-houses, etc.

2. Measurement of Liquids and Gases.

Appliances for measuring liquids may be divided into two classes: (1) those for determining the density of liquid bodies, and (2) those for determining their quantity. Such appliances are called *meters*. The terms meter, register, counter, and indicator are frequently used interchangeably, but they are not exactly synonyms. An indicator gives audible or visible notice of results or conditions; a register records; and a meter measures distance, capacity, power, etc., giving results in volumes or other units, and it may have an indicator for *reading*, or a register for *recording*, its action.

Hydrometers.—Instruments for testing the relative density of liquids are known, in general, as hydrometers, and specifically, according to their respective uses, as alcoholometers, oleometers, lactometers, etc., which terms usually indicate the peculiar kinds of fluids they are designed to test. The hydrometer was known to the ancients, and its invention is ascribed to Archimedes; the principle on which it is based is well illustrated by the familiar experiment which employs the hen's egg for verifying the strength of lye in soap-making and of brine in curing meats. The common hydrometer consists essentially of an elongated graduated stem combined with a hollow bulb, and so weighted at its lower end as to cause the stem to remain upright when the instrument is placed in the liquid to be tested (*pl.* 122, *figs.* 1, 2). The zero mark of the scale is adjusted to the point on the stem to which the instrument sinks in distilled water or any other liquid which is taken as a standard. The depth to which it sinks in the liquid to be tested indicates on the graduated stem its specific gravity. As the density of liquids varies with the temperature, in all cases diminishing as the temperature increases, the graduation of the hydrometric scales must be based on a standard degree of temperature, and this is generally assumed to be 60 degrees. If the liquid at the time of testing is cooler or warmer than that thermometric degree, the indication on the hydrometer must be added to or subtracted from according to a scale which varies with the nature of the liquid. These temperature correlatives are determined by experiment, and a printed scale for each particular kind of hydrometer may be obtained with the instrument. Hydrometers intended for testing liquids of a wide range of variableness, such as alcoholic liquors, are generally provided with a number of weights to be added to the normal weight of the instrument where the liquid to be tested is so dense as to buoy the hydrometer beyond the range of the graduated stem. Thus a hydrometer to test whiskies and high wines is usually calculated for liquids containing alcohol

from "proof" upward, and when the alcoholic contents of the liquid are below "proof," a weight is added to counterbalance the increased density of the liquid; and this weight is necessarily accounted in connection with the indication on the graduated stem. Some hydrometers are graduated with the zero mark—that is, the point of submersion in distilled water at 60° temperature—placed midway on the length of the stem, so as to be used for liquids both lighter and heavier than water; and these are technically known as "specific-gravity" scales.

Rain-gauge.—The annual amount of rainfall is very unequally distributed over the earth's surface. This is due to various conditions which exert a definite influence on the amount of precipitation. For measuring the amount of rainfall over a given surface there is employed the rain-gauge, variously known as an ombrometer, udometer, pluviometer, etc. A simple device for this purpose consists merely of a funnel, from 5 to 7 inches in diameter, inserted in the neck of a bottle, the rain collected in the bottle being measured in a graduated glass (*pl.* 122, *fig.* 3). Self-recording rain-gauges are very delicate and accurate instruments of more or less complicated construction.

Current-meters.—Among the best-known current-meters is Pitot's tube (*fig.* 4), which acts by the ascension of water in a bent tube whose funnel-shaped lower end is presented squarely to the current, the indications being read by a float or graduation on the vertical part of the tube. Woltmann's dynamometer current-gauge (1790) consists of several spiral vanes on a shaft carrying an endless screw, which rotates a series of geared wheels and a register. On being placed in a current, the vanes assume a position perpendicular to the flowing water, and their rotation actuates the clock-work mechanism of the register by which is indicated the velocity in miles per hour, the rate or force being deducted from the rotation of a given time. These current-gauges, being dependent on the velocity of the liquid in motion, all partake essentially of the nature of dynamometers or force-measuring machines. They are, however, used to determine the quantity of water carried by any given current, the velocity of the moving water being obviously the main factor in the determination of the quantity. Figure 5 exhibits a current-meter for use in small rivers and streams to show the rate of flow of the tide, or the number of gallons flowing from a reservoir.

Tide-gauges.—The tide-gauge, also called thallassometer and marigraph, is a device used in harbors to measure the rise and fall of the tides. A simple form of tide-gauge is represented by the graduated spar, whose lower end is suitably secured in the bed of a stream, the graduations indicating the height of the water. An arrangement similar to the tide-gauge is the nilometer, for measuring the rise of the Nile during its periodical floods. It consists of a pillar, 16 cubits high, marked with the necessary divisions for ascertaining the proportionate increase or decrease of the flood. The rise of the Nile has always been a subject of great anxiety to the Egyptians, for upon the periodical saturation of the ground

and the coating of soil left upon it depends the success of the year's husbandry. From the earliest historic period nilometers have been placed in prominent positions in Egypt to enable the officers to watch the rise of the Nile, which was proclaimed by criers; and formerly the amount of taxation to be imposed upon the country was determined by this means. The nilometer at Cairo has been erected for many centuries, but it is not so ancient as the one at Elephanta, which consists of a staircase descending to the Nile between two walls. One wall has engraved on it a series of marks representing the height to which the water has risen on certain occasions.

Self-registering Tide-gauges have a mechanism by which the ebb and flow of the tides are automatically registered or indicated. The self-registering gauge of Sir William Thomson (*pl.* 122, *fig.* 6) is described as follows: Supported by a stand is a clock which, besides keeping time, actuates beneath it a drum whose rotation winds upon itself, with a uniform movement, a continuous web of paper from another cylinder. In position on the stand alongside the clock are two pulleys, one of small and the other of comparatively large diameter. Passing over the large pulley is a cord, to whose lower end is fastened a counterbalanced float-weight which rises and falls with the tide. On one end of the pulley-shaft is a pinion which engages a gear-wheel on the shaft of the small pulley, from which is suspended a weighted ink-bottle carrying a pen. These rise and fall with the movement of the float, and the pen traces a continuous record on the paper around the drum in the form of zigzag lines whose angles correspond with high-water and low-water periods, the horizontal distance between each two angles indicating the intervals between two high or two low tides.

Water-meters, as distinguished from hydrometers, are devices for mechanically measuring the amount of water or other liquid received or discharged through an orifice. The forms of such meters are various, and they may be divided into seven classes: (1) those in which the fluid passes through a horizontally-revolving case with a peripheral discharge, or a stationary case containing a horizontal turbine-like wheel which delivers a known amount of water at each rotation; (2) those which are operated by the pressure of the water acting on rotary pistons whose action is on the principle of the rotary engine (p. 260), and which are the converse of the rotary pump (p. 332); (3) the Archimedian screw (p. 327); (4) those with a reciprocating piston in a cylinder of known capacity, on the principle of the ordinary steam-engine; (5) the meter-wheel; (6) the pulsating diaphragm, which displaces the water from its respective sides alternately; and (7) the bucket-and-balance, or those in which reservoirs of known capacity on the respective ends of the beam are alternately presented to catch the water and are depressed and emptied as they become filled.

Figures 7 and 8 exhibit a water-meter whose principle of action is the reciprocation of pistons or plungers. The machine consists of two

parallel cylinders, in each of which are two piston-heads connected by a stem and acting as a double plunger. The space between the pistons is filled with water and contains the mechanism that actuates the water-valves, which are slide-valves. Under the stem or central space of each piston is placed the slide-valve of the opposite piston, so that the motion of each piston actuates the valve that admits water against the other piston, the action being reciprocal. Each stroke of the pistons is marked on a counter or register; the meter is therefore of the positive kind, and furnishes no water unless working properly. The counter, attached to the top of the meter and operated by a ratchet movement, registers in cubic feet—one foot being $7\frac{48}{100}$ gallons, U. S. standard—and is read in the same way as the registers of gas-meters, the dials recording tens, hundreds, thousands, ten thousands, hundred thousands, and millions of cubic feet. The motion of the pointers is not continuous, as they move a little and stop, and again move at the next stroke of the plungers; the flow of water, however, is continuous. The inlet-pipe, which is not shown in the Figures, is in a line with the eduction-pipe and on the opposite side of the meter. The machine measures with great accuracy the quantity of water or other liquid passing through it.

Gas-meters.—Gas-measuring machines are represented by the gas-meter, a device for measuring and recording the quantity or volume of passing gas. The wet meter (*pl.* 122, *fig.* 9), invented in 1807 by Samuel Clegg and improved in 1815 by Samuel Crossly, consists of an outer box partially filled with liquid (water, alcohol, or glycerin) to the level of about half the height of the box. Within this box is journalled an axis carrying a series of buckets, each capable of containing a definite quantity of gas, which is admitted through a pipe at the central part of the meter. The gas, which causes the buckets to rise successively and which maintains a continuous rotation, passes out through a pipe at the upper part of the meter, the quantity being measured by a series of multiplying gear-wheels, which derive their motion from the axis on which the buckets are secured, and which register on a series of dials hundreds, thousands, ten thousands, and hundred thousands of cubic feet. Valves are arranged to cut off the supply of gas when the water in the meter rises above or falls below certain limits. The dry meter, invented in 1820 by John Malam and improved in 1838 by Defries, operates on the principle of a bellows of known capacity alternately filled with gas and emptied, the quantity of passing gas being indicated by a register. The pressure of the gas is the motor, and the changes of motion are effected by induction and eduction valves, much as in a steam-engine. Gas-burners are tested by the meter shown in Figure 10. To insure a uniform and steady light the test-meter is made with three diaphragms, and to show the internal working parts is glazed in front and on top. The dial is so devised as to exhibit by one-minute observations the hourly rate of gas consumed.

3. Measurement of Time: Horology.

Historical.—Of the many inventions devised by the genius of man, none are of more general interest than those designed for dividing the day into fixed periods. The first divisions of time were doubtless made by observing the positions of the sun during his daily course, and by discovering that surrounding objects throw shadows of different lengths and in different directions as the day advances. The result of these observations was the invention of the sun-dial, though the date when it was first employed cannot be fixed. The first recorded mention of its use is in Isaiah xxxviii. 8: "Behold, I will bring again the shadow of the degrees, which is gone down in the sun-dial of Ahaz, ten degrees backward."

As the intervention of clouds and the advent of night obstructed the light of the sun, the usefulness of the dial was limited, and something was demanded that should without interruption indicate the time during all hours of the day. This demand was met by the invention at an unknown date of the "water-clock" or *clepsydra*, which is supposed to have been of Egyptian origin. The oldest of which there is record is that mentioned by Plato (400 B. C.). The soft notes of flutes, played at regular intervals by this ingenious mechanism, indicated the time of day. Figure 1 (*pl.* 124) shows a form of clepsydra used in Egypt about 200 B. C. The water runs through a pipe (*H*) into a funnel (*A*) and drops into the cylinder *E*. The stopper *B* is for regulating the water-supply, while the superfluous water escapes through the pipe *I*. A floating piston moves a vertical rack which gears into a wheel bearing the hour-hand. The day of the Egyptians (from sunrise to sunset) was divided into twelve hours. To regulate the flow of the water according to the length of the day (depending upon the season or latitude), the stopper *B* was adjusted by the stalk *D*, which was for this purpose provided with an index for any day in the year. The most celebrated clepsydra of which there is a recorded description was that presented to Charlemagne by the caliph Haroun-al-Raschid A. D. 807. Copper balls equal in number to the hours of the day dropped, one every hour, into a basin, and the termination of the hour was indicated by the sound produced by each ball. This clepsydra had twelve doors, which opened one after another every hour, and from each door as it opened there issued a rider with a lance in his hand. The several riders retained their positions outside the opened doors until the appearance of the twelfth rider, when all simultaneously withdrew, closing the doors with their lances. It is also stated that the clock was ornamented with moving figures of many kinds.

Absolute precision in time-keepers, however, was not attained until there were invented clocks consisting of a series of wheels driven by weights and cords and controlled in their movements by regulating devices. With the construction of such instruments the history of the time-keepers of the present day begins, though it cannot be ascertained when the first wheel-and-weight clock was made. Pacificus, an archdea-

con of Verona in the ninth century, has been named as the inventor, though it is also asserted that this style of clocks was derived from the Arabians. Records of the twelfth century indicate with more certainty the existence of real clocks at that period. The first of which we learn particulars that indicate clocks of any similarity to those of modern construction was presented in 1232 by the sultan of Egypt to the Emperor Frederick II. "It resembled a celestial globe, in which the sun, moon, and planets moved, being impelled by weights and wheels, so that they pointed out the hour, day, and night with certainty." This seems to indicate that the fundamental principle of modern clocks is of Saracenic origin. We find that in the thirteenth century there were many tower clocks with striking works in the church steeples of Italy; in 1288 a striking clock was built for the Westminster tower with money derived from a fine imposed upon a chief justice. With the beginning of the fourteenth century such clocks became more general. The first detailed description of a clock dates from 1370, when a German, Heinrich von Wick, was employed by Charles V. of France to make a turret clock for the king's palace (*pl.* 124, *fig.* 2). Although controlled by a "balance" (the pendulum not yet being invented), it had a striking resemblance to the turret clocks of recent years. It was the bell of this clock that gave the signal for the massacre on St. Bartholomew's Day. Portable time-keepers, in the form of watches impelled by the tension of a spring, were made early in the sixteenth century in Nuremberg, and it seems that Peter Hele invented them; they were known by the name of "Nuremberg eggs." (See Vol. II., p. 268.)

A new epoch begins with the application of the pendulum and hair-spring to control the action of the escapement, as these appliances provided the means for the attainment of the remarkable perfection of modern time-pieces. Christian Huygens (1629–1695) invented the pendulum clock, and Robert Hooke (1635–1703) invented the hair-spring about 1660.

Modern Time-keepers may be conveniently treated by considering (1) the *motor*, a mechanism that furnishes the impelling power whose source may be either a weight or a spring; (2) the *train*, a series of toothed wheels impelled by the motor to move pointers over a dial for the purpose of indicating the hour and its subdivisions; (3) the *regulator*, an arrangement for controlling the speed of the train, so that the hour and its subdivisions may be correctly indicated (pendulum and balance-wheel, with hair-spring); (4) the *escapement*, which gives the impulse for the controlling oscillations of the regulator (Figure 4 represents most of the essential parts of a weight-clock: *P*, *A*, cord and drum, is the motor. The train consists of the wheels *B*, *C*, *D*, *E*, *F*, *G*, and the escapement of the escape-wheel *H* and the anchor *K*); and (5) *electric clocks*, whose controlling force, either directly or indirectly, is electro-magnetism.

The Motor.—Time-keepers are divided into three classes—namely, (1) those whose impelling power is a weight; (2) those whose impelling power is a spring; and (3) those whose impelling power is an electro-magnet. In

the first class the attraction of the earth acts upon a weight suspended to a cord or a chain, and the weight, by drawing down the cord, revolves a shaft upon which the cord is wound. In the second class a contracted spiral-shaped spring by its endeavor to resume its original expanded condition acts upon a drum and causes it to revolve. In the third class the attractive or repelling force of an electro-magnet acts upon a piece of iron and causes it to oscillate. The first and second classes are appropriately treated together, while the third class requires a separate consideration.

Weight-motor.—Figure 4 (*pl.* 124) shows the arrangement of a weight-motor in its simplest form. *A* is a drum on whose periphery is wound a cord (*P*). The drum is fixed upon a steel shaft whose projecting front end is filed square to receive the key when the clock needs winding. The great wheel *B* of the train rides loosely upon the arbor of the drum, of which the ratchet-wheel *f* is a part. A click (*k*) is screwed to the great wheel and is pressed into the teeth of the ratchet-wheel by the spring *o*. It is obvious that if a weight bears upon the cord *P*, it will turn the drum as well as the wheel *B* to the left, while if the drum is moved to the right for the purpose of winding the clock, the click will yield under the pressure of the spring *o* and allow the wheel *B* to remain in its position, where it is held by the next wheel of the train. It is clear that by this arrangement the clock will have to stop during the process of winding; stoppage, however, is avoided by the maintaining power (*fig.* 3) invented by John Harrison (1693–1776), which is applied on all better grades of clocks. To the above-described mechanism a second large ratchet-wheel (*a*) is added; the large ratchet-wheel, like the great wheel *B* (*fig.* 4), rides loosely upon the arbor of the drum, and is located between the small ratchet-wheel and the great wheel *B*.

The click *k* that drops into the teeth of the small ratchet-wheel, to allow the winding of the clock, is fastened to the large ratchet-wheel; there are also fastened to the large ratchet-wheel, in two opposite positions, two springs (*ss'*), so as to press against two opposite spokes of the great wheel *B*; into the teeth of the ratchet-wheel a second click (*C*) falls loosely, and is held in this position by an arm fastened against the frame of the clock. When the weight and the cord act upon the drum, the small ratchet-wheel by means of the click (*k*) moves the large ratchet-wheel, whose two springs (*ss'*), pressing against the spokes of the great wheel *B*, bend and attain a certain tension. If now, when the winding process takes place, the drum is turned to the right, the tension of the springs *ss'* will have the tendency to move the large ratchet-wheel to the right and the great wheel to the left. The large ratchet-wheel is prevented from moving to the right by the click *C* dropping into its teeth, which, yielding under the pressure of the springs, move the train.

Spring-motor.—Figures 9 and 10 (*pl.* 123) show the arrangement of a spring-motor under two different conditions, wound and unwound. It consists of a cylindrical capsule *b*, called a "barrel;" of a spring *a*, a

tempered band of steel of spiral shape (*pl.* 123, *fig.* 4); and of an axis, called an "arbor," upon which the barrel loosely turns. The spring, as shown in Figure 9, is placed in the barrel, against whose inner periphery it presses tightly. One end of the spring is hooked into a projecting pin of the arbor, and the other end is hooked into a pin of the barrel. Figure 9 shows the spring in its expanded state in the barrel, and Figure 10 in its contracted state when wound up on the arbor.

There are two ways of using this arrangement as the impelling medium. If, as in Figure 10, the arbor is made immovable, the barrel will follow the outer end of the expanding spring in the direction indicated by the arrow; while, if the barrel is fixed, the arbor will follow the movement of the inner end of the spring and turn in a direction opposite to that indicated by the arrow. The rotations thus produced may be transferred to the train of the time-keeper in two ways: (1) by means of a chain, one end of which is hooked to the periphery of the barrel, while the other portion of the chain is wound upon the arbor of the great wheel; and (2) by gearing directly into the next wheel of the train, the great wheel, which may be one piece with the barrel. Of the first-named arrangement Figure 4 gives the perspective and Figure 5 the side view. When the barrel turns under the expansion of the spring, it will wind up the chain on its own circumference, and thereby revolve the great wheel. In Figure 5, f is the barrel, with a large portion of the chain wound up on its periphery. The arbor a' of the barrel is held in position between two metal plates A, B by its pivots; b' is the arbor of the wheel to be moved by the chain, and bears besides the wheel the so-called "fusee," which is also held in position by the plates A, B. The fusee is a cone (s), with a groove running spirally over its surface from the smallest diameter to the greatest diameter, to which latter the chain is fastened at b'. Projecting through the plates is the fusee-arbor, a part of which is filed square to receive the winding key. If the key is turned to the right, the fusee will revolve and draw the chain from the barrel into its groove, since this turns the barrel, while its arbor remains fixed; hence the spring will be wound around the arbor. When the spring is entirely wound and has attained its greatest tension, the chain in the groove has reached the smallest diameter of the fusee. As the spring runs down and its tension becomes less, the chain gradually unwinds toward the larger diameter of the fusee s. By this arrangement a constant power is attained, the shape of the cone being so formed that the diameter of the fusee increases in the proportion that the tension of the spring relaxes while expanding. In Figure 4, A is the barrel and spring, B the chain, C the fusee, and D the great wheel of the train.

The same conditions that are met with while winding the weight-clock present themselves in the use of the fusee and chain; that is, the tension of the spring while being wound cannot act, as the fusee during this operation is turned backward; hence it is necessary to apply the already-described maintaining power to any time-keeper with fusee and chain.

This is unnecessary, however, when the barrel and the great wheel become one part, since the barrel turns in the same direction as its arbor while the winding of the spring takes place, as demonstrated in Figure 10 (*pl.* 123). Figure 7 represents the upper part of such a barrel, which shows also the click *s* and ratchet-wheel *r* for the purpose of winding the spring round the arbor. The ratchet *r* is fixed to the arbor, which projects through the barrel. If, now, arbor and ratchet-wheel are turned in the direction indicated by the arrow, the spring inside the barrel is wound upon the arbor, and is prevented from turning back by the click *s*, which, being fastened to one of the plates between which the barrel is placed, is pressed into the teeth of the ratchet-wheel by the spring *f* (*fig.* 7), which produces the condition explained in Figure 10, and causes the barrel to turn in the direction in which the arbor is turned while winding the spring.

The Stop-work.—In addition to the ratchet-wheel and click, the barrel is provided with another arrangement (*fig.* 8) called the "stop," whose object is to prevent the spring from being wound up too tightly. Upon the cap of the barrel is placed another smaller wheel *u*, half of whose periphery is toothed; the arbor by which the winding is effected carries a single-toothed wheel (*s*), which at every revolution rotates the wheel *u* to the extent of one tooth. If in a few turns the solid portion of the wheel's periphery comes in contact with the tooth of the wheel *s*, the latter cannot be turned any farther and the spring has attained its desired tension. While the spring is running down, this mechanism repeats its movements in the opposite direction, and comes again to a stop when *s* comes in contact with the other side of the solid portion of the wheel *u*; this last stop prevents the spring from losing its tension below a certain fixed point, and makes winding necessary to renew the impelling power.

The Train.—As defined in the general classification (p. 360), the train is a series of toothed wheels impelled by the motor for moving the pointers or hands over a dial to indicate the hour and its subdivisions. Figure 4 (*pl.* 124) shows a pendulum-clock train, of which the great wheel *B* has already been mentioned (p. 361) in conjunction with the motor. This wheel has one hundred teeth, and gears into the pinion *C* of the centre-wheel *D*, which has eighty teeth; the centre-wheel gears into the pinion *E* of the third wheel *F*, which has sixty teeth; and finally, the third wheel gears into the pinion *G* of the escape-wheel *H*. The number of teeth of the pinions *C*, *E*, *G* are respectively 8, 8, and 10. The centre-wheel *D* makes one revolution every hour, consequently the escape-wheel *H* $\frac{80}{8} \times \frac{60}{10} = 60$ revolutions. To effect this is the object of the escapement and pendulum, which in their co-operating action prevent the escape-wheel from revolving uninterruptedly by stopping each tooth of the wheel twice during its complete revolution. In the Figure the escape-wheel, having thirty teeth, will therefore be compelled to make sixty stops at every revolution, and, moreover, the escape-wheel, as it is required to make this number of stops at each revolution, will have to be stopped at intervals of one second.

Motion-work.—A continuation of the train is the motion-work (*pl.* 125, *fig.* 4) for indicating the time by the hands on the dial; it is generally placed outside on the clock-frame, and is operated by the projecting arbor of the centre-wheel. Terminating in the pinion *A*, and fitting tightly on the protruding arbor of the centre-wheel, is a tube which carries the minute-hand, and makes, with the centre-wheel, one revolution every hour. The wheel *B* is also fastened to a tube, which fits loosely over the tube of the wheel *A*, and carries the hour-hand. The hour-hand, however, must travel twelve times slower than the minute-hand, which is accomplished by the intermediate wheel and pinion *B*, *C*, the number of teeth of *A*, *B* being so calculated as to reduce the speed of *C* in that proportion.

The Regulator has for its object the controlling of the duration of the periods of interruption to which the escape-wheel is subjected while it completes one revolution, and by which the train is compelled to move only with a speed necessary to revolve the pointers, so that they shall correctly indicate the time. For obtaining this result the regulating force is either the gravitation of a pendulum or the elasticity of a delicate spiral-shaped spring in combination with a balance-wheel, called the "balance."

The Pendulum.—The oscillations of the pendulum determine the length of the intervals between the interruptions of the escape-wheel. The number of these oscillations in a given time depends on the length of the pendulum; shortening it increases their number, while lengthening it makes their number less. By this means there can be produced on the escape-wheel the number of interruptions necessary for the correct indication of the time by the train. The pendulum in its simplest form consists of a rod of metal or of wood bearing on its lower end a mass of metal called the "ball," and on its upper end a spring to suspend it. Pendulums of such simple construction are affected by the variations of temperature, which change their length and thereby effect a change in the number of oscillations required to be made in a given time; they can, therefore, be used only on time-keepers which are not expected to keep absolutely correct time. A clock to be an instrument of precision must have a pendulum whose length cannot be changed by the varying temperature of the atmosphere. To attain such a result is the object of the compensated pendulum invented by George Graham (1703–1751). The property possessed by different metals to expand differently when subjected to the same degree of heat has suggested an ingenious method of avoiding the effects of the change in temperature.

Compensated Pendulum.—Figure 7 (*pl.* 124) shows such a compensated pendulum: it consists of five iron and four brass rods, the iron rods in the Figure being shaded darker than the brass rods. The first and longest two iron rods are fastened above and below to a horizontal bar; the lower metal bar holds two brass rods, which carry on their upper ends a third horizontal bar which also carries a pair of brass rods. The latter are finally connected on their upper ends by a fifth narrow bar, from the middle of which is suspended a longer iron rod which extends through the two lower hori-

zontal bars and carries on its end the pendulum-ball, shaped like a lens, so that the air may offer the least possible resistance to the pendulum's oscillations. If the two outer iron rods expand, they will lower the second horizontal bar, and with it the first pair of brass rods; by the expansion of the latter, however, the third bar, which bears the second pair of iron rods, will be raised, and since the expansion of brass is greater than that of iron, the third bar will be raised proportionally to a greater extent than the second bar was lowered. If in this manner we follow the action of the entire system of iron and brass rods, we shall find that the expansion of the iron rods downward will be neutralized by the expansion of the brass rods upward, which latter expansion raises the horizontal bars to which the iron rods are suspended to such an extent that the position of the pendulum-ball will remain unaffected by the change of temperature. The exact proportion in the length of the iron and brass rods must, of course, be determined by careful measurements of the material used if the object of the whole arrangement is to be realized. The pendulum is suspended by a thin metal spring (shown in the Figure), and receives from the escapement the impulses for the continuation of its oscillations in a manner explained on p. 368.

Spring and Balance Regulator.—For portable time-keepers—watches, for example—the balance and hair-spring become the regulator (*pl.* 123, *figs.* 1, 2, 3, 6). To the arbor *O*, in Figure 6, are fastened a delicate spiral-shaped spring called a "balance-" or "hair-spring," and the balance *s*. The outer end of the hair-spring is fastened to the stud *f*. (See perspective view, *fig.* 1, *U*, *f*.) The arbor *O*, being pivoted and resting in bearings, is permitted to oscillate to the right and to the left. The hair-spring when at rest will keep the balance in a fixed normal position. If, however, the balance be turned away from this point, say to the right, the elasticity of the hair-spring will bring it back to, and cause it to pass beyond, its normal position in consequence of the inertia thus imparted; after the balance has passed its normal position, the elasticity of the hair-spring becomes a force opposing the further progress of the balance, thereby exhausting the inertia of the balance and bringing it for a moment to a standstill, when it will be forced by the accumulated tension of the hair-spring to move to the left, when the inertia received from the hair-spring again carries it beyond its normal position, and thus keeps it oscillating until the resistance of the air and the friction of the bearings of the balance bring it gradually to a complete standstill in its normal position. The number of oscillations depends upon the tension of the hair-spring, and becomes greater in number if by a given width and thickness the spring is shortened, and less if it is lengthened; thereby an easy means is given to obtain a certain number of oscillations in a fixed time.

Figure 6 shows an old arrangement for this purpose. A section of a toothed wheel *a* gears into a partly-toothed wheel *b*; *a* has an extension *c*, and is movable in the grooves *d*, *e* of the rounded metal piece *d*. The extension of *a* bears at *c* two pins, between which the outer coil of the

hair-spring loosely plays. If now the little pointer *r* of the wheel *b* is moved toward *R*, the pins at *c* will move to the right, and thereby lengthen the hair-spring and decrease the number of oscillations of the balance; if the pointer is moved toward *A*, the pins at *c* will move in the opposite direction and shorten the hair-spring, thereby increasing the number of oscillations.

Figure 3 (*pl.* 123) shows a later form of regulation; *r* is the balance-wheel and *bb* the hair-spring, whose end *c* of the outer coil is fastened at *d*. The balance-arbor is held in an upright position by the "bridge" *K*, *R*, *A*; on the upper side of the bridge, just over the centre bearing of the balance *r*, a small round steel plate *ce* is fastened by two screws; this plate fits into the beveled edge of a steel ring (*ss*) which has two arms—a long pointed one (*f*) and a short one (*g*)—and the ring is held in any given position by its friction against the little steel plate *ce*. The long arm serves as a pointer for the graduated part *RA* of the bridge. On the end of the lower side of the arm *g* are two pins, between which the outside coil of the hair-spring is placed. If the arm *f* is turned toward *R* the hair-spring is lengthened, if turned toward *A* it is shortened, and there is thus produced the effect either of retarding or of accelerating the oscillations of the balance.

Compensating Balance.—Changes of temperature will affect the balance and hair-spring in the same manner as they affect the pendulum, and produce variations in their dimensions, which of course will also either retard or accelerate the vibrations of the balance if the temperature rises or falls. To neutralize this effect the compensating balance invented by John Harrison is employed, the principle of which is also based upon the difference in the expansions of different metals under the same temperature. In Figure 2 the balance is not of one continuous piece, but is cut into halves *ab* and *a'b'*, each of which is fastened on one side to the arms *cc*, leaving the entire semicircle of each half of the balance free. Each half of the balance is made of brass and steel strips, lying parallel and fused together, as is shown in the Figure. The outer strip is of steel, and the inner strip is of brass. Since under a rising temperature the brass strips will lengthen more than the steel strips, the free ends of the balance will tend to move toward the centre, thereby making the circumference of the balance smaller; consequently it would vibrate more rapidly if at the same time the change of temperature had not also lengthened the hair-spring and thereby retarded the oscillations. A sinking of temperature will naturally have the opposite effect and enlarge the circumference of the balance, thereby neutralizing the accelerating effect of the shrinking hair-spring. On the periphery of the balance are screws (*i*), by which its vibrations may be controlled. If they are screwed more or less deeply into the balance, its circumference will be greater or smaller and the number of oscillations will be changed accordingly, thus making the arrangement for shortening or lengthening the hair-spring as described above unnecessary. This manner of adjusting the balance is generally

adopted for marine time-keepers. The adjustment of the compensation is further effected by bringing the screws *i* more or less near the free ends of the balance. This is the purpose of the extra screw-holes indicated in the Figure. Moving the screws toward the free end will further the retarding tendencies of the compensation, while if screwed near to the fixed end the accelerating tendencies are effected.

The Escapement.—The escapement serves two purposes: it controls the progress of the train and gives the necessary impulses to the regulator to continue its oscillations. The oldest escapement known is the "verge" or "crown"-wheel. We find it in the oldest clock known (see Von Wick's clock, *pl.* 124, *fig.* 2), and it is still in use in watches, although its claim to accuracy is entitled to but little consideration as compared with the escapements of a later date. It consists of the escape- or crown-wheel *AB* (*pl.* 123, *fig.* 11) and of the balance-staff *ab*, called the "verge," which has two smooth projections (l, l'), called "pallets," at an angle of 95.02 degrees. The distance between the pallets from centre to centre is equal to the diameter of the crown-wheel. The drawing gives a view of the escapement as it is placed in a watch, and shows the verge with the hair-spring, but omits the balance. The escape-wheel has either eleven or thirteen teeth; in the Figure it has thirteen: the escape-wheel, being impelled by a wheel of the watch-train which gears into its pinion *t*, moves in the direction of the arrow, but is obstructed in its progress by the pallet l at the tooth α. The tooth α presses against the pallet and turns it upward high enough to escape. By this operation the entire verge has turned and moved the pallet l' downward, which now impedes the progress of the wheel at the tooth β on the opposite side. The tooth β will now lift the pallet l' until it escapes also, then the tooth α drops against the pallet l, which will repeat the same operation. In this manner the escape-wheel is alternately stopped in its progress by the two pallets l, l', whereby it sets the verge and its balance into an oscillating motion, which is controlled by the hair-spring in a manner already demonstrated. When one tooth escapes and another drops against a pallet, the momentum of the balance will still move the pallet in a direction opposite the teeth, thereby compelling the crown-wheel to move slightly backward until the hair-spring reverses the vibration of the balance.

Recoil Escapement.—Escapements that show the above feature are called "recoil" escapements, which have the tendency to gain by an increase of the impelling power and to lose when it becomes less—a condition which is reversed in escapements to be described hereafter. The reason of this is that the increase of power offers a greater resistance to the recoiling action of the pallet, thereby exhausting the momentum of the balance earlier and reducing the arc of the vibrations, while by a decrease of power the tooth of the crown-wheel becomes a less impeding factor to the pallet, and the balance is allowed to move in a greater arc.

Dead-beat Escapement.—Figure 12 shows the Graham escapement (invented by George Graham), whose prototype evidently is the anchor

escapement (invented by Hook about 1675), which is also a recoil escapement. In Graham's escapement the escape-wheel stands still while the pallets are moving, and therefore it has received the name of "dead-beat" escapement. The Graham escapement consists of the escape-wheel *A* and the anchor *Dxmn*. The anchor is supported at *D*, from which point it is kept in oscillating motion by a pendulum not indicated in the drawing. The escape-wheel moves in the direction of the arrow, one of its teeth *c* pressing against the inclined end-surface of the pallet 1; if now the oscillating pendulum moves the anchor to the left, the tooth *c* will glide over the inclined surface and leave the pallet; at that moment the tooth γ will drop at *a* on the pallet 2 and rest on it until the anchor moves to the right, when it will glide over the inclined surface *a*, *b* of the pallet and escape, and the tooth δ will drop to the pallet 1. While a tooth is gliding over the inclined surface of a pallet it exercises against the anchor a pressure which is transmitted to the pendulum by an arm fixed to the arbor *D*. This pressure gives the impulse to the pendulum for the continuation of its oscillations. The anchor thereby serves its double purpose, first by transmitting the impulses to the pendulum, and secondly by causing the step-like movement of the escape-wheel by interrupting its progress at such intervals as are determined by the length of the pendulum.

It is the form of the pallets which makes the Graham escapement a "dead-beat" escapement. The curve of the pallets is that of a circle having its centre at *D*; a tooth, if it drops on a pallet, strikes it beyond the inclined surface and rests on its curved portion, this being a section of a circle with its centre at the support of the anchor, and will keep the escapement-wheel at a standstill until the tooth glides over the incline. We have observed that in the verge escapement an increase of the impelling power causes the balance to increase its oscillations; this effect is reversed on the Graham and all other "dead-beat" escapements. While resting on the curve of the pallet the pressure of the escape-wheel does not materially oppose the progress of the anchor; if, therefore, the impelling power is increased, it will act upon the driving surface of the pallet with a greater force and give a greater impulse to the pendulum, thereby enlarging the arc of its oscillations. This will diminish the number of its oscillations, and of course will make the clock go slower, while obviously a decrease of the impelling power will have the opposite effect, and make it go faster. The Graham escapement gives good results when all parts of the clock can be well protected and inclosed. For tower clocks, however, it does not give the desired result. The air-currents, striking under changing force or direction the large and exposed hands, will either retard or accelerate the movements of the clock. In one case it will react upon the pendulum by decreasing the arc of oscillation and make the clock go slower; in the other case it will diminish the arc and make it go faster. The gravity escapement, invented by E. B. Denison (Lord Grimthorpe) in 1854, removes this evil very successfully.

Double Three-legged Gravity Escapement.—In the double three-legged

gravity escapement exhibited in Figure 5 (*pl.* 124), the gravity impulse pallets *aa'* are two bent plates pivoted as nearly as possible to the suspension point of the pendulum; *bb'* is the locking wheel, made up of two thin plates, each having three long teeth or "legs," and fastened on the escape-wheel arbor a little distance apart; between them, near to the arbor, at equal distances are placed three pins, called the "lifting" pins. Each of the impulse pallets has at its bend an arm (*ff'*), the tip of which approaches the pins above and below the escape-wheel arbor; at the lower extremity the impulse pallets are prevented from going beyond a fixed point by checking pins (*gg'*). Both of the impulse pallets are placed inside of the space between the locking-wheel plates *b* and *b'*. At their bend each of the pallets has a block (*ss'*). The pallet to the right has the block on its front, the other pallet has the block (indicated in the Figure by dotted lines) on its opposite or rear side. In order to show the locking wheel, part of the pendulum is cut away.

The locking wheel turns from left to right; in the Figure one of its "legs" *d* rests on the front block *s*. The tip of the arm *f* of the front pallet is now in contact with one of the pins, which has lifted the arm into its present position. The pendulum moves in the direction of the arrow, and pushes the pallet *a* far enough to the right to release the leg *d*, which rests on the block *s*. The moment the leg *d* escapes from the block, the leg *e* will drop against the block *s'* of the pallet *a'*; while simultaneously the lifting pins have moved also, and one of them has raised the pallet *a'* by carrying along the tip of its arm *f'*, while at the same time the pin that rested against the tip of the arm *f* has moved away from it, thereby setting free the pallet *a*, the entire weight of which now presses against the pendulum, which soon begins to move in the opposite direction, receiving its impulse from the weight of the pallet. On its return it does not find the pallet *a'* leaning against the pin *g'*, the position in which it parted from it, for the pallet has been lifted up a short distance by a lifting pin; while the pallet *a* still follows the pendulum until it is stopped by the checking pin *g*. The pendulum, in continuing its oscillations, pushes aside the pallet *a'*, releases the locking wheel at *s'*, and is locked again at *s*. The weight of the pallet *a'* will now give an impulse to the pendulum, while the pallet *a* is lifted up and ready to impart another impulse as soon as a leg at *s* is again unlocked. Since the pallets are always lifted to the same height, it is evident that the impulses imparted to the pendulum must also remain unchanged independent of any change that may take place in the impelling power of the train. To prevent any jarring of the locking wheel by a too rapid movement of the same, there is placed on the arbor of the locking wheel a "fly," which is held in its place by the friction of a spring, by which the fly is permitted to continue its movement for a moment when the locking wheel has stopped at its respective block.

Cylinder Escapement.—An escapement of good qualities, and specially adapted for watches subjected to hard usage, is the cylinder escapement,

invented by Tompion or by Graham about 1700 (*pl.* 123, *fig.* 13). The escapement-wheel *A* varies greatly in form from the two preceding types; the wedge-shaped teeth are elevated above the surface of the wheel's body and supported by stalks, as represented in the engraving. The arrangement which produces the step-like movements of the escape-wheel is a cylindrical steel shell, half of which is cut away to the extent shown in the engraving, and turns on its axis in bearings at *dd*. The outside diameter of the cylinder fits loosely between the spaces of the teeth, and the teeth themselves fit loosely into the inside diameter of the cylinder. At *B* the cylinder receives the balance and the hair-spring in a manner already described. We assume that the oscillating cylinder *B* is moving from the left to the right; we now perceive that the tooth just begins to press against the lip *a* of the cylinder; while progressing, the inclined tooth will glide along the lip *a*, thereby imparting the impulse for the vibrations of the balance. As soon as the tooth has left the lip *a* the tooth β will drop against the outside surface of the cylinder near the lip *b'*, and will then rest against the cylinder until the tension of the hair-spring reverses its vibration; then the tooth will glide along the lip *b'*, thereby imparting another impulse to the balance in the opposite direction. It will be seen that in this manner, alternately, either the inside of the cylinder encloses a tooth or the entire cylinder is placed between the space of two teeth, and that a tooth which comes into action first falls against the outside periphery of the cylinder on the right side, resting there until it can pass the entering lip *b'* of the cylinder, then remaining inside of the cylinder until it can pass also the exit-lip *a*. The inner and outer surfaces of the cylinder being parallel circles oscillating around their centres, it is obvious that the escape-wheel while resting against either surface must come to a perfect standstill, which makes it a "dead-beat" escapement.

Lever Escapement.—An escapement far superior to the preceding is the lever escapement (*fig.* 14), which was invented by Thomas Mudge about 1770. The balance, after it has received its impulse from the escapement, is no longer in contact with the escapement, but moves entirely free, and therefore it is called a "detached" escapement. It is of the greatest importance that the balance be relieved of friction as much as possible, in order to reduce to a minimum the elements that obstruct its vibrations, an advantage which is more or less gained by all detached escapements. Figure 14 shows the lever escapement of a Jurgensen watch; the escapement exhibits a great similarity to the Graham "dead-beat" escapement (*fig.* 12); the escape-wheel *C* (*fig.* 14) moves in the direction of the arrow, its slender but blunt teeth being greatly inclined. The anchor *A* is fastened to its arbor at *x*, and its pallets *1* and *2* are sections of a ring that has its centre at *x*; *l,u* is the lever, fastened to the anchor; at the left the lever terminates in a fork (*k*), and at the right in a counterpoise (*u*). The two pins, *v* and *w*, called "banking pins," limit the extent of the lever's movements; the arbor of the balance carries a small steel wheel *i*, called the "roller," with an upright pin *s*, called

the "impulse pin;" when the balance is oscillating the roller *i* and the impulse pin *s* participate in its oscillations. The impulse pin enters the fork *k*, which follows the oscillations by moving to and fro. In the Figure the impulse pin has entered the fork to its deepest point, and a tooth of the escape-wheel has just passed to the end-surface, called the "driving face," of the pallet *d*, which tooth consequently will glide over the face of the pallet and force it upward, thereby pressing the fork at *i* against the impulse pin, and imparting an impulse to the balance and moving it to the left. The pin *s* will be carried beyond the limited point of the fork's movement, and will leave the fork. At this moment the tooth leaves the pallet *d*, and the tooth *y* falls against the inner curved surface of the pallet *l*, called the "locking surface;" there the tooth remains until the balance reverses its vibrations and the impulse pin enters the fork again at *i*; then the anchor is moved in the opposite direction, and the tooth, after leaving the locking surface, enters the driving face *b* of the pallet *l* at *a*, glides over it, and presses the fork at *l* against the impulse pin, imparting an impulse to the balance while moving to the left. As soon as the tooth leaves the pallet *l*, the tooth ε drops against the locking surface of pallet *d*, where it is detained until released to act upon the impulse face of the pallet. In this manner one tooth after the other exercises its pressure against the driving faces of the pallets and keep's up the vibrations of the balance. The lever escapement has now become a favorite one for watches, and, no doubt, if made with sufficient care, is preferable to the cylinder escapement; but if made in a neglectful manner the defects are rarely as easily corrected as they are in the simple arrangement of the cylinder escapement.

Chronometer Escapememt.—The most perfect of the detached escapements is the chronometer escapement (*pl.* 125, *fig.* 6), invented by Pierre le Roy about 1769, and perfected by Thomas Earnshaw and John Arnard about 1780. It seems to be so well adapted to the peculiar movement of a ship on the open sea that it is the only escapement employed for marine time-keepers. Before explaining the action of this escapement we will describe the parts of the mechanism and their relative positions. The balance and hair-spring, not shown in the engraving, are mounted on the arbor *d*; the arbor carries a roller *S*, *R*, called the "impulse roller," which has an indentation *p*, *a*, *q*, whose upper part is curved, while the lower part is straight and provided with a stone of highly-polished surface *q*, *a*, called the "impulse pallet." The arbor has a second smaller roller (*i*, *l*), with a projection (*k*), made also of stone and called the "discharging pallet." The escape-wheel *S'*, which is impelled in the direction of the arrow, has inclined pointed teeth—straight on one side and curved on the other—and approaches, in its proper position, the impulse roller just close enough to allow its periphery to move free along the curved side of the teeth; *m*, *m*—*n*, *n* is a combination of two springs called the "detent;" the longer one to the left is called the "blade of detent," and has at *c* a projection called the "locking pallet," on which the tooth *y* of the escape-wheel rests.

The blade of detent rests against the shoulder of a screw-head to limit its approach to the escape-wheel and to adjust the position of the locking pallet *c*. At the lower end the detent is fastened by two screws in a fixed position, while a small portion of the upper end terminates in a bend (*n*), called the "horn of detent;" the shorter spring of the detent *m*, *m* is made of gold, and is attached to the blade of the detent some distance below the pallet *c*, and runs parallel with the blade a little beyond the horn of detent *n*, against which it rests.

If we now assume that the balance and rollers are vibrating and the detent pallet *k* is moving toward the terminal of the detent, the pallet will come in contact with the projecting end of the gold spring *m*, thereby bending it to the right and passing it, while the blade of detent is retained in its position by the shoulder of the screw-head *r*, against which it rests. When the balance returns, it brings the detent pallet again in contact with the end of the gold spring, bending it this time to the left and passing it again. Now, however, the detent blade also will yield and move the locking pallet *c* to the left, thereby releasing the tooth of the escape-wheel, which at that moment moves in the direction of the arrow; the escape-wheel is, however, intercepted in its progress by the impulse pallet *a*, against which the tooth *α* strikes, and follows until the pallet has moved far enough to set the tooth free. The detent, however, having returned to its normal position, the tooth β will drop on the locking pallet *c* and stop the wheel again. When the balance returns, the detent pallet will again pass the gold spring, and the action just described will be repeated. It may be unnecessary to state that the blow struck against the impulse pallet adds to the momentum of the balance for continuing its vibrations; the fact that the balance receives but one impulse at every other vibration makes it a more perfectly detached escapement than the lever escapement. If, however, proper performance of its functions is expected, it must be made in all its parts and proportions with the greatest care. For watches it is less adapted, since the movements of the body subject it to certain jerks, which interfere greatly with its proper action. For marine chronometers, however, it fills nearly all wants perfectly, and leaves but little to be desired. Figure 5 (*pl.* 125) shows a marine chronometer whose train is impelled by two main-springs and two toothed barrels, both being separately wound. This precaution secures to the chronometer an impelling power of one spring, in case one or the other of them should break, although the breaking of the spring would interfere with its time-keeping qualities. The rest of the train is hidden from view by a plate which shows the escapement. The hair-spring has the form of a cylindrical spiral, and the balance is a compensating one.

Striking Clocks.—An exceedingly admirable and ingenious mechanism is the striking-work attached to many clocks in general use. The date of this simple invention cannot be ascertained. The oldest clock (Von Wick's) whose details are known is provided with a striking-work whose essential parts are still in use, and which is known as the "locking-plate" strik-

ing-work (*pl.* 125, *fig.* 1). The train consists of the wheels *B*, *C*, *D* and the pinion *E*, which carries the fan or "fly" for preserving uniformity in the time which elapses between each stroke of the hammer. The great wheel *B* is impelled by a cord and weight bearing on the drum *A*, and has a series of pins to lift the lever *K* and hammer *L* which strikes the bell to announce the hour when the minute-hand points to twelve. This is accomplished by the striking mechanism as follows: the wheel *C*, which is driven by the great wheel *B*, has fixed to its arbor a notched cam *d*, called the "locking-cam." The locking-lever *J* with its bearing at *f* has also a notch (*g*), whose outline fits in the notch of the locking-cam, where it rests when the striking-work is inoperative. To prevent the continuous running of the train, the pin *e* on the pin-wheel *D* rests against a projection extending upward from the locking-lever *J*. The dotted line at *H* indicates a lever which is gradually raised by the time-keeper just before the completion of an hour. This lever has also a projection extending upward to the same height as the projection on the locking-lever *J*. The projection on *J* has on its lower portion a horizontal opening or slot which gradually rises to the pin *e*. The moment this opening comes in line with the pin, the pin-wheel *D* is set free by allowing the pin *e* to pass through the slot of the projection; but the pin is immediately stopped in its progress by the upright projection of the lever *H*, and is detained until the instant the hour is completed, when the lever *H* drops and releases the pin and the entire train begins to move. The incline of the locking-cam raises to the height of its circumference the locking-lever *J* until the wheel *C* has made one revolution; the locking-lever then falls into the notch *g* of the locking-cam *d*, and the pin is again stopped by the projection of the locking-lever and the train is arrested. At each revolution of the locking-cam the hammer *L* strikes one blow.

To produce the number of blows corresponding to the hour indicated on the dial is the purpose of the locking-plate or "count-wheel" (*fig.* 2), which has on its circumference indentations corresponding in number to the twelve hours on the dial. The locking-plate is so fastened to the clock-frame that when the train is moving a pinion fastened to the arbor of wheel *C* revolves the plate. A rigid arm on the bearing *f* of the lever *J* rests in an indentation of the locking-plate; if now the train is set going, the arm will be raised out of the indentation of the revolving locking-plate; after the locking-cam *d* has made one revolution, the arm rests on the blank circumference of the locking-plate and keeps the locking-lever *J* in a raised position until the locking-plate has revolved far enough to allow the arm to fall into another indentation of the locking-plate, which movement allows the locking-lever to sink into the notch of the locking-cam. It is obvious that the spaces between the indentations of the locking-plate must be so arranged as to correspond to the number of hammer-blows required to indicate the hour shown by the hands of the dial. One of the indentations has double the width of any other. This indentation is for the first hour, which requires but one blow, after which the train stops.

Repeating Striking-clock.—The great disadvantage of the locking-plate striking-works is that if accidentally the clock strikes at any time between hours, the number of blows will no longer correspond to the time indicated on the dial. This disadvantage is obviated by the repeating striking-clock (*pl.* 125, *fig.* 3). The counting-wheel above described is replaced by the "hour-snail" *C*, which has on its spirally-curved circumference steps corresponding in number to the twelve hours on the dial. The rack *D* is a segment of a ratchet-wheel movable at *m*, and has an arm *r* which, under the pressure of a spring *o*, falls against the hour-snail *C*, and the clock is then ready to strike. At each revolution the short arm of the gathering pallet *F*, which revolves once at every blow of the hammer, catches into and moves one tooth of the rack *D*. The rack-hook *E* prevents the rack from falling back when the gathering pallet leaves a tooth. The gathering pallet continues to move the teeth of the rack, one after another, until the rack-hook *E* reaches the last tooth of the rack; then the longer piece, the "tail," of the gathering pallet will be intercepted by the pin *a* of the rack, and this pin will bring the train (not indicated in the Figure) to a stop. When the clock begins to strike the hour, the arm *r* rests against a step of the snail *C*, which step corresponds to the hour of the dial; the gathering pallet *F*, before it is stopped by the pin *a*, makes one revolution for each blow of the hammer. For example, at the sixth hour the pallet will make six revolutions and the clock will strike six. The tail of the gathering pallet remains at the pin *a* until a few minutes before the completion of the next hour; then the lifting piece *G* is raised by the pin of wheel *H*, which makes one revolution every hour. The lifting-pin *G* raises the rack-hook *E* and releases the rack *D*, whose arm (*r*) again drops against the hour-snail *C*. The lifting-piece *G* has on the end of its upper arm a projection extending through the opening *b* of the clock-frame; as soon as the rack-hook is lifted out of the rack, the pin of the pin-wheel *D* (*fig.* 1) rests against this projection, and there remains until the lower arm of the lifting-piece *G* (*fig.* 3) has left the lifting-pin of the wheel *H*. The lifting-piece then drops, the pin-wheel is set free, and the striking process already described is repeated. This time, however, the clock will strike seven, the hour-snail having been moved one step further after striking the sixth hour. A lever *J*, bearing against the under side of the lifting-piece *G*, has attached to its outer end a cord *s*, which, if pulled, raises the lifting-piece, and the clock strikes the hour just passed and repeats it any time, since the hour-snail retains its position up to the beginning of a new hour. This feature becomes useful at night when the time cannot be seen, as by pulling the string the hour last struck can be ascertained by the striking of the clock.

The Strasburg Cathedral Clock (*pl.* 124, *fig.* 6), an admirable production of the clock-maker's skill, was constructed (1838–1840) by Schwilgué to replace a similar older work: it consists of three turret-like parts, of which the central one is 46 feet high. The part to the right in the Figure is circular, and contains winding stairs for reaching the various stories of

the central or main turret. In front of the base, in the centre, stands a large celestial globe which illustrates one hundred and ten of the constellations whose stars can be seen in the sky with the naked eye. This globe rotates in unison with the rotation of the starry firmament. On the base and behind this globe is a large rotating calendar-disc which indicates the movable feasts of each year, and, as the calendar rotates, Apollo, who stands beside it, points with a small rod to the existing day. In the centre of this calendar-disc, which is nine feet in diameter, is a smaller disc which indicates the rising and the setting of the sun, the course and phases of the moon, and the appearance of the eclipses of the sun and moon. On both sides of the calendar are mechanical arrangements indicating the year, the cycle of the sun, the golden number, the Roman indiction, the epacts, and Easter for the current year. Above the calendar, on a projection of the base, seven chariots slowly pass by in the course of a week—Sunday, Apollo with the horses of the sun; Monday, Diana with a stag; Tuesday, Mars with war-horses (chargers); Wednesday, Mercury with lynxes; Thursday, Jupiter with thunderbolt and clouds; Friday, Venus with doves; and Saturday, Saturn with a chimera. The base next carries the "lion gallery," so called from two lions, one of which holds in its claws the escutcheon of the city of Strasburg and the other a helmet. In the centre of this gallery is the clock dial-plate which indicates the time. Beside the clock stand two genii, one of whom strikes the quarter hours upon a bell, and the other hourly turns an hour-glass. The lower division of the central turret contains an orrery, upon which are represented the annual movements of the planets Mercury, Venus, Earth, Mars, Jupiter, and Saturn. In the division next above the clock, on a starry firmament, the gradual waxing and waning of the moon is illustrated by means of the rotation of a ball, one-half of which is white and the other half black. In the succeeding higher division is an effigy of Death holding in one hand a scythe and in the other hand a bone. On each side of this figure is placed a bell: at the time of the quarter hour the figure of a child enters a side-door, and, turning to one of the bells, strikes once upon it with a rod, and then disappears through another side-door; at the time of two quarters, or half hour, a youth (huntsman) appears in the same manner and strikes twice with an arrow upon the bell; three-quarters of the hour are indicated by a man (warrior), who strikes thrice upon the bell with a sword; and finally, at the fourth quarter, or full hour, an old man emerges from the side-door and strikes the bell with his crutch, whereupon the arm of "Death" is raised and slowly strikes the hour upon the larger of the two bells.

In the uppermost division stands the form of the Saviour holding the banner of Victory in his left hand and giving the sign of blessing with his right hand, which is movable. At the twelfth hour the twelve apostles, one after another, pass by the Saviour, toward whom, in passing, they turn to receive the sign of blessing. The apostles having passed, the sign of blessing is repeated to the visitors, a large number always being present

in the cathedral. On the apex of the turret, to the left in the Figure, is a cock, which, as the apostles pass by, flaps his wings, moves his head and tail, puffs up his neck, and crows thrice. The ornamentations in the highest point of the central turret are composed of the figures of Josiah, of the evangelists, of seraphs with musical instruments, etc. The smaller turret contains the weights of the supplementary works, which, being unlocked from time to time by the central mechanism, actuate the moving figures. The works of the central turret set in motion the entire mechanism, which is wound every eight days. The stairs lead not only to the central part, but also to the large dial-plate (16 feet in diameter), which is placed over the portal of the cathedral, on the south side, and which indicates the hour, the day, and the week.

Electric Clocks may be divided into two classes: (1) primary or automatic clocks, whose impelling power is exclusively the electric current, and which are controlled by their own pendulum; and (2) secondary electric clocks, or time telegraphs, whose source of impelling power is also exclusively the electric current, but which are operated by a separate pendulum-clock. Primary electric clocks were invented in 1840 by Alexander Bain, and though many ingenious inventions have brought them to a high state of perfection, they are of little general interest. The secondary electric clock, however, is an important advance in electric time-distribution, and through its great utility has made rapid strides toward general adoption. It has for its purpose the distribution of correct and uniform time to localities however far apart. The secondary clock is not of itself a time-keeper, but is controlled, through the medium of electric wires, by a well-regulated pendulum-clock called the "master clock," from which it receives the time telegraphed; hence the name "time telegraph." It was invented by Steinheil in 1839, and by Wheatstone and Bain in 1840. The pendulum-clock, to operate the time telegraph, needs a contrivance to close and to open an electric battery, which connects the time telegraph by electric wires with the master clock; such an arrangement is called the "contact-maker" or "circuit-breaker." When the contact-maker closes the galvanic battery, an electric current passes through the clock and energizes an electro-magnet, which attracts a piece of iron, thereby moving the train of the time telegraph. Contacts are made as often as needed, according to the construction of the electric dial. Most of them move every minute, and some move every second.

Bain's Electric Clock, shown in Figure 1 (*pl.* 126), although one of the earliest types, has since its invention been one of the leading devices in various modifications, and even many recent arrangements retain its characteristic features. When the galvanic battery is closed at the master clock, the electric current passes over the connecting wires through the coil of the electro-magnet E, and becoming magnetized attracts the soft piece of iron called the "armature" a, which is movable on pivots at x and is free to oscillate. On its lower extremity the armature bears a pawl h which glides over the teeth of the ratchet-wheel R when the armature is

attracted and moves toward the poles of the electro-magnet; the moment the electric battery is opened at the master clock, the spring *f* brings the armature back to its former position and the pawl moves the ratchet-wheel to the extent of one tooth. The arbor of the ratchet-wheel gears into a clock-train which moves the hands in front of a clock-dial; a second pawl h^1 prevents the retrograding of the ratchet-wheel when the armature moves toward the poles of the electro-magnet.

Garnier's Electric Clock.—An electric clock with features quite distinct from those of Bain's is the one which was invented in 1847 by Paul Garnier of Paris (*pl.* 126, *fig.* 3), and which, though more complicated, is more durable in construction and more reliable in its action than Bain's clock. The armature *a*, suspended over the poles of the electro-magnet *E* by a metal rod and drawn down when attracted, moves the lever which has its fulcrum at *x*; the pawl *s* moves the ratchet-wheel *R* while the pawl s^1, which is rigid to the lever *h* near its fulcrum, enters a space between the teeth to prevent the wheel from moving more than one tooth at a time. The pawl s^2 prevents the ratchet-wheel from making a retrograde movement.

Siemens & Halske's Electric Dial is noted for the peculiar arrangement of its armature (*fig.* 2), which moves in its bearings at *x*, and has its extremities in such position, relative to the north and the south pole respectively, that they are vibrated, similar to the movement of a scale-beam. The ratchet-wheel *R* is moved similarly to that of Bain's clock, but with the action reversed; while the movement in Bain's clock was effected by the retrograde movement of the armature, the power of the retracting spring being used for that purpose, in the Siemens clock the ratchet-wheel is moved at the time the armature is approaching the poles of the electro-magnet *E*,—a feature which, as we shall learn later, is not at all beneficial to the clock. To prevent the ratchet-wheel from moving more than one tooth at each impulse, the lever *h* has at *z* a little tooth-shaped projection which enters the space between the teeth of the ratchet-wheel and stops its further progress.

Stöhrer's Electric Clock.—An essential change was introduced (1847) by Stöhrer of Leipsic (*fig.* 4), who was the first to use a permanently-magnetized armature, by which he attained advantages not possessed by any previous device. One end of the soft-iron armature *aa* is rigid, and carries the arbor of the anchor resting in its bearing at *z*, while the other end plays between the poles of the electro-magnet *E*, *E*; one of the poles of a permanent magnet *M* is placed opposite and in close proximity to the end of the armature, which is fastened to the shaft at *a*; the permanent magnet thereby induces magnetism in the armature, whose extremities are transformed into two opposite magnetic poles. If now an electric current passes through the coil of the electro-magnet and that end of the armature which is moving between its poles has a south polarity, the armature will be repelled by the south pole and attracted by the north pole. To effect a movement of the armature in the opposite direction, the current

passing through the electro-magnet is reversed to change its polarity; this repeated successively will of course produce an oscillatory movement of the armature. The manner of transferring the movement of the armature to the clock-train is also a more appropriate one than those above described. For this purpose the well-known recoiling anchor-escapement is employed, which, without providing for any extra check for the escape-wheel, moves one tooth after another by the oscillations of the pallets of the anchor in the usual manner. This clock possesses many advantages; no retracting spring is needed to remove the armature from the poles of the electro-magnet, to overcome whose tension necessarily requires considerable loss of magnetic energy, and no extra provision is needed to keep the armature in position when inactive, since this is done by the magnetism induced in the armature. The Stöhrer system has been brought to a high state of perfection by Dr. M. Hipp, whose modification has become a favorite one in Europe.

All the above-described time telegraphs, which are characterized by a certain similarity, depend upon the action of one armature, and as they are similarly constructed, so are they similarly defective. The movement of the armature is not one of a gradual progress, but is instantaneous, and is suddenly checked when in very close proximity to the poles, where the magnetic attraction is nearly the greatest. This action has proved to be a serious defect in all time telegraphs, owing to the resulting violent blows, which inevitably impair the mechanism.

Spellier Time Telegraph.—The electro-magnetic escapement invented in 1876 by L. H. Spellier has removed the above-noted defects of electric clocks. Figure 5 (*pl.* 126) shows the arrangement of this escapement. *A* is an iron wheel divided into six equal segments, each segment representing an armature, and *B* is the escapement-wheel, with inclined teeth, corresponding in number to the armatures of the wheel *A*, both wheels being rigid on one shaft. *L* is a weighted lever which presses by means of a little roller (*P*) into the teeth of the escapement-wheel *B*. The electro-magnet *M* attracts the armature as soon as the electric current passing through the coil is closed. This armature takes its position right over the pole of the magnet, as represented in Figure 5. When in this position the lever *L* is raised, and presses the roller *P* against the upper part of a tooth of the escapement-wheel *B*. As soon as the circuit is broken the weight of the lever moves both wheels in the direction indicated by the arrow and places them in the position shown in Figure 6. The armature *1* is now removed from the pole of the magnet, while the armature *2* has closely approached it. When the circuit is again closed, armature *2* will be attracted and the roller *P* will raise the lever and pass over the apex of the next tooth of the escapement-wheel, where it will remain until the circuit is again broken, when the same action as described will be repeated. It will be seen that by this arrangement not the slightest blow is imparted either to the armature or to the escapement-wheel, for there is no impact, nor is the armature submitted to the objectionable instantaneous check

when it arrives at its halting place, but it will describe over the poles, before coming to a standstill, a few short, rather decided vibrations.

The making and breaking of the electric circuit, which are apparently the easiest of all operations in time telegraphy, proved for a long time to be the weakest and most troublesome point. Two difficulties are to be met. When the electric circuit is broken, there appears at the point of separation a spark, which gradually oxidizes or entirely burns away the metal and prevents the passage of the current. For a long time this was the most serious evil presented in the proper action of electric clocks, but it was finally completely removed by devising a means of suppressing the formation of the spark (Hipp and Spellier). For the passage of the electric current contacts should be sufficiently energetic to make them positive; the contact-maker is operated either by the pendulum or the escapement-wheel, according to the requirements of the electric dial, but neither possesses sufficient energy to secure a firm enough contact, especially if a large number of clocks are dependent upon them. Garnier resorted to the expedient of a separate clock-work, which was very ingeniously set going by the master clock and had sufficient power to make a firm contact. Spellier (1884) succeeded in devising a means by which the escape-wheel of the master clock develops sufficient energy for a firm contact (*pl.* 126, *fig.* 6). The escape-wheel *W* of the master clock moves in the direction of the arrow, its arbor bearing rigidly a long arm (*H*) having on one end a pin (*P*). While the arm revolves with the escape-wheel, this pin comes in contact with the inclined projection of the spring *R*; when this takes place the electric current passes from the galvanic battery, with which the arm is connected by wires, through the contact-spring *L* to the escape-wheel arbor, thence through the contact-arm *H* into the spring *R*, which is connected by wires with any number of electric clocks, and returns from the last of them to the battery. Ordinarily, the escape-wheel would not have sufficient power to force the pin over the inclined contact-surface of the spring *R*, and to accomplish this is the purpose of the "power-accumulator" *AB*; the arbor carries, besides the contact-arm *H*, a cam (*A*), against whose curve the weighted lever *B* is pressed by a little roller *R*. It will be seen that just now the roller of the lever presses against the incline *I* of the cam, thereby imparting additional power to the shaft of the escapement-wheel, and assisting in overcoming the obstruction offered by the tension of the contact-springs. The moment the pin has passed the projection of the spring, the roller *R* of the weighted lever reaches the lower part of the cam, and the roller is gradually raised as the escapement-wheel revolves; and this operation is repeated at the next contact of the contact-pin. It is obvious that there is a gradual storing up of a portion of the power expended by the escape-wheel during the course of its revolutions, which power is returned to the escape-wheel at the proper moment for the purpose above indicated.

Electric Time-distribution in Cities.—Large cities, in which there is general or extensive time-distribution, must be divided into districts and

must have a separate circuit in each district. For this purpose Hipp constructed a master clock, which, besides keeping the train and pendulum moving, very ingeniously set in operation each minute a clock-work which has as many contact-makers as are needed for a certain number of circuits without interfering in any way with the proper action of the clock. Hipp's construction, although exceedingly reliable in its operation, is somewhat complicated and rather expensive.

General Time-distribution.—The "time-distributor" (*pl.* 126, *fig.* 13), a less complicated arrangement constructed by Spellier for the same purpose, has also a number of contacts (six in the cut), and is operated by clock-work impelled by a weight (*fig.* 13). The clock-work is released by the action of an electro-magnet, which is electrically connected with an ordinary master clock for that purpose. The cord and weight of the drum drive the train 1, 2, 3, 4, 5, 6, 7, 8, 9, 10; the arbor of wheel 10 has a "fly" to regulate the speed. The arbor of wheels 8, 9 carries a mechanism called the "locking-frame," which arrests the train when inoperative. The arm b of the locking-frame C rests upon the armature A of the electro-magnet M. Once every minute the master clock closes for one second the circuit of an electric battery whose current actuates the electro-magnet M, which attracts its armature A; thereby the arm b of the locking-frame looses its support and the train which is released begins to move. The armature being attracted for one second only, will be brought back to its former position of the weight W. The wheels 6, 7, whose arbor operates the contact-maker and which drive the wheels 8, 9, make one revolution in operating the contact-maker while the wheels 8, 9 make four revolutions, which the armature A, having returned to its original position, would prevent were the locking-frame not so arranged as to shorten during its first three revolutions and to lengthen at the completion of its fourth revolution. Figure 9 shows the locking-frame and the principle of operation. The brass block B is fastened to the arbor of wheels 8, 9 (*fig.* 13), and revolves with it. The frame has four projections ($PPPP$) having holes in which the rods RR of the frame FF slide. The frame, being a little longer than the block B, is allowed to make a lateral movement. Two springs (ss') fastened to the block press against the frame at n, and press the right side of the frame, if free, close up to the block B. To the left of the frame a short projection carries a little roller (r) which is placed just opposite the arbor a of wheel 6 (*fig.* 13).

This arbor bears a cam K, which, when in the position shown in the Figure, presses the frame toward the armature; when the arm b rests on the armature the train of the time-distributor stops. The moment the armature is attracted by the electro-magnet the arm b loses its support, and both the cam and the locking-frame move in the direction indicated by the arrows; the little roller r then leaves the cam, and the frame is pressed by the springs ss' toward the arbor a. This of course moves the arm b near to the block B, and allows the arm b while revolving to pass the armature until the cam again comes into contact with the roller and

presses the frame in the opposite direction, thereby moving the arm *b* toward the armature, by which the arm will be stopped. This process takes place in about four seconds, in which time the arbor of wheel 6 operates the contact-maker, of which Figure 8 (*pl.* 126) shows a separate view. The contact springs *s*, *s*, *s*, *s*, *s*, *s* are fastened to the front plate *T* of the time-distributor, and are insulated from it by hard-rubber blocks *H*. The centre contact *C* is fastened to the arbor of wheel 6 and revolves with it. Every rubber block has a double set of springs arranged as shown in Figure 10, which also shows the centre contact and its attitude to the contact springs.

One pole of the battery is connected with the front plate *T* of the time-distributor, and thereby electrically communicates with the centre contact *C*, while the other pole connects with the different clock circuits, each of which terminates in its corresponding set of contact springs. If now the centre contact *C* revolves, it will, during the course of its revolutions, come in contact with each set of contact springs, thereby sending an electric current in successive order through the different clock circuits connected with their respective contact springs. Figure 12 shows in a general way a complete arrangement for electric time-distribution. Once every minute the master clock *R* closes the battery *B* and energizes the electro-magnet *M* of the time-distributor *T*, which magnet attracts the armature *A* and thereby releases the arm *b* of the locking-frame, whereupon the train of the time-distributor, being then started, revolves the centre contact *C*.

One pole of the battery B^1 is connected with the frame of the time-distributor *T*; the other pole connects with the different clock circuits (two in the diagram): when the centre contact *C* comes in contact with the first set of contact springs 1, it closes the circuit of the clock-line *L*. The current, following the course indicated by the arrows, passes from the battery to the frame *T* of the time-distributor; thence to the centre contact *C* into the contact springs 1; then to the different clocks in the line *L* and the sentinel *S* back to the battery B^1. The same process takes place in the clock circuit L^1 as soon as *C* comes in contact with the contact springs 6, etc.

As electric clocks have for their object the indication of correct time, any break in the time service will mislead; hence automatic means should be provided for the immediate detection of any interruption. For this purpose Spellier devised an apparatus called the "sentinel," which gives audible notice of any trouble as soon as it appears. This sentinel (*pl.* 136, *fig.* 11) consists of a spring clockwork (*x*) and of an electro-magnetic escapement (*A*) whose magnet is in the circuit of the electric dials. The escape-wheel *B* has on the front of each tooth a pin (*c*); the arbor of the hour-wheel *h* of the spring clock carries a lever (*C*) which is movable on the arbor, but is held spring-tight by a spring (*e*). The operation of the escapement is as follows: When the electric current actuates the escapements of the electric dials in the circuit, it also actuates the escapement *A* and the pin *c*, toward which the lever *C* is moved by the arbor of the

hour-wheel, and pushes the lever backward and passes it. Should the current, however, fail to pass (on account of a broken wire, for example), the escapement *A* and all the clocks will cease moving, and the arbor of the spring-clock hour-wheel will carry the lever *C* to the contact-point *d*, whereupon there is closed a separate battery which rings a signal-bell and announces the pending trouble. If the sentinel escapement is made a little more sluggish in action than the escapements of the electric dials, any weakening of the battery will first be shown at the sentinel, which will fail to operate, and the lever will then be carried to the contact-point *d*, and will ring the bell before the battery is sufficiently weak to affect the clocks in the circuit.

Synchronizing Clock.—The first attempt to use an electric current for obtaining uniform time was made by Steinheil, who for electrically correcting ordinary clocks devised what is known as the "synchronizing" system, which has been developed by other inventors and is still employed. The clocks in line are each provided with an electro-magnet and are electrically connected with a master clock. At fixed periods, ranging from one to twenty-four hours (in the latter case at noon), there is sent by the master clock through the magnets of the clocks in line an electric current which attracts their armatures and actuates a mechanism which corrects the hands of the clocks not indicating correct time. As the subordinate clocks require the same attention and are subject to the same accidents as ordinary clocks, this system is less desirable than one purely electrical.

Clocks Wound by Electricity, or "self-winding" clocks, as they are called, are wound automatically by an electric motor, which continues to act as long as the galvanic battery operating the motor remains strong enough to furnish a sufficient current to drive the motor, and do not require the personal attention that must be given in winding spring- and weight-clocks by hand. The self-winding clock promises to become a valuable factor in the synchronizing method of electric time-distribution.

Time-balls have become a popular convenience for indicating the moment when the sun passes the meridian of a place whose time is accepted as the standard. A staff erected at an elevated position is provided with a large ball having a hole through its centre to allow the ball to glide down the staff. The ball is held at the upper end of the staff in a fixed position by an appropriate mechanism, which is so arranged that through the action of an electro-magnet the ball can be set free and glide down the staff. The electric current, which passes through the magnet of the time-ball and causes it to fall, is sent daily exactly at noon from an astronomical observatory. To mariners in seaports the time-ball has become an especially valuable means for determining the correctness of their chronometers.

4. MACHINES FOR THE MEASUREMENT OF SPACE.

As no precise idea can be formed of the length of a line except by comparing it with another line of known length, the necessity of having

recourse for the interchange of ideas to some definite measure of distance seems to have been perceived in the earliest ages. Such standards were easily derived from Nature, and were intelligible alike to all mankind; hence originated the hairbreadth, the span, the foot, the cubit, and other measures of extent taken from parts of the human body or from other natural objects which, though not of an absolute and invariable length, had a certain mean value sufficiently definite to answer all the requirements of a rude state of society. As civilization advanced, the necessity of adopting more precise standards became recognized; the inadequacy of such measures as the foot, the cubit, etc. to convey accurate ideas was rendered most apparent in their application to multiplied measures or to the estimation of great distances. To meet this inconvenience, other methods of reckoning were resorted to, but they amounted only to descriptions more or less vague and not to measures; thus in ancient authors we frequently read of a day's journey, a day's sail, etc.; and in many parts of the Continent of Europe at the present time it is the custom of the peasantry to reckon itinerary distances by hours.

The English standard of lineal measure is the *yard*, which is divided into 3 feet, and the foot is subdivided into 12 units or inches. The multiples of the unit are the pole or perch, 198 inches; the chain, 792 inches; the furlong, 7920 inches; and the mile, 63,360 inches; but for itinerary distances the pole and furlong are now scarcely employed, distances being generally computed in miles and yards. The French system of measures, introduced during the Revolution, has for its theoretical standard the length of a quadrant of the earth's meridian through Paris. The unit of measures of length is the *metre*, which is $\frac{1}{10000000}$ part of the quadrant, and equivalent to 39.370091 inches of the English yard.

A variety of appliances have been invented from time to time for mechanically determining quantities of length and area, and though these have found but a limited application in actual practice, a glance at their character and construction may properly be here included.

Odometers.—An odometer is a device attached to a wheel for measuring the distance passed over in travelling. Odometers may be attached to the wheel of a carriage or may be driven by hand; in the latter form they are called "perambulators." Various kinds of machines have been constructed for this purpose both in ancient and in modern times. An odometer described by Vitruvius (*pl.* 127, *figs.* 1, 2) consisted of a narrow drum-wheel (*B*, *fig.* 1) fixed to the inner side of the hub of the carriage-wheel *A*, and had one small projecting tooth (*B*, *fig.* 2), which at each revolution turned one tooth of a cog-wheel (*C*) having four hundred teeth. This cog-wheel also carried a single projecting tooth which engaged a horizontal ratchet-wheel (*D*) having holes (*e*) equal in number to the number of miles in an ordinary day's journey. In each of these holes of the third wheel was placed a small stone ball, and each ball was brought consecutively to a channel (*F*) in the case, through which it dropped into a metallic vase (*G*), thus audibly indicating the transit of one mile by the

sound of a dropping ball. By the numerical proportion of the gearing, every four-hundredth revolution of the drum-wheel *B* caused one complete turn of the cog-wheel *C*, whose projecting tooth moved but one tooth of the ratchet-wheel *D*, whereby a ball dropped through the channel *F* into the vase *G*; at the end of the journey the number of balls in the vase indicated the number of miles travelled. The wheels of the carriage or chariot were made of such a diameter that every revolution would advance the vehicle 12½ feet; thus in four hundred revolutions they passed over 5000 feet, or the ancient Roman mile. The diameter of the wheels was therefore 4 feet 2 inches. Among the effects of the emperor Commodus there were carriages which not only measured the road, but also pointed out the hours. Odometers are sometimes employed in modern hacks and carriages for casual hire. A recent French instrument invented by Bruet and called a "compteur mécanique," or calculating-machine, not only reckons the distance travelled, but also indicates the exact sum of money due the driver. Figure 3 shows a carriage odometer which is attached to the spokes of a carriage-wheel, whose revolutions actuate an endless screw in contact with a toothed wheel by which the distance travelled is indicated on the dial. A similar apparatus is used on bicycles, and is called a "cyclometer."

Perambulator.—The perambulator is a machine which may be drawn along by a person on foot, and is employed in mapping districts of country. In one form it consists of a wheel 8¼ feet in circumference journalled in the end of a stock, so that it may be lifted from contact with the ground; on the axis of the wheel is a pinion which works another pinion on the end of a rod having at its upper part an endless screw which moves a train of gearing that gives motion to two hands of an index, registering the distance to miles, furlongs, rods, and yards. Two revolutions of the wheel measure one rod.

In this class of appliances may be included the measuring-wheel or "circumferentor," employed for measuring the periphery of a carriage-wheel to find the length of tire required. It consists of a small wheel of known circumference graduated on its peripheral edge and journalled in a stock or holder. The zero mark of the measuring-wheel is placed at a marked spot on the carriage-wheel, around which it is caused to travel; the number of revolutions of the small wheel and such a fraction of a revolution as there may be, indicate the perimeter of the carriage-wheel. Of more complicated construction is the "lumber-measurer," by which the number of superficial feet contained in boards of different lengths can be estimated. Within a case in a vertical position is a toothed disc, which, by being made to pass along the surface of the lumber, actuates a mechanism that indicates on a dial the superficial contents. Projecting from the bottom of the case and terminating under the centre of the disc, is a sleeve which enables the operator to begin measuring with the edge of a board directly under the centre of the disc.

Pedometer.—The pedometer is an apparatus for registering the number

of steps taken by a pedestrian and for ascertaining the distance he travels. In exterior appearance the pedometer resembles a watch, and may be carried in the watch-pocket, or may be hung on a belt, or secured to a buttonhole. The pedometer has a dial, and a hand which is so counterweighted that at each motion of the person in walking the weight pulsates and advances the hand one degree. It requires no winding, but begins its operation as soon as the wearer takes a step, and quickens, moderates, stops, or resumes its work exactly as the wearer steps, without requiring the slightest attention or imposing on the pedestrian a special or non-interrupted gait; it not only indicates long distances, but also adds up short distances made at different times, and shows the exact total. To simplify the reckoning, the dial is usually divided into twelve spaces, each space representing one mile; but after having marked that distance the hand continues moving around the dial. To ascertain if the instrument is regulated correctly, it is necessary for the wearer to walk over a certain distance—a mile, for example. If the hand has marked one division, the pedometer is correct; if the hand marks less or more than one division, the instrument can be regulated by means of a screw, which is turned to the right or to the left respectively.

5. MACHINES FOR THE MEASUREMENT OF MOTION.

Measurement of Power.—Appliances for measuring power of any kind—for example, the strength of men and of draught animals, the force exerted through machinery, etc.—are called "dynamometers," which may be divided into two general classes: (1) those for the measurement of power exerted by a prime mover, and (2) those for the measurement of power transmitted. In the first class are those contrivances in which the power is exerted on a lever or an elliptical spring, and in the second class are those mechanical devices in which the force transmitted from a prime mover or the amount of force consumed in driving a machine or a series of machines is determined. They involve, generally, the expedient of interposing between the motor and the machine, as a medium through which the power is to be transmitted, some combination of springs and a scale on which are recorded the degrees of static force corresponding to different states of tension, and sometimes also an automatic mechanism for making periodical record of the marking of the index on the scale, or some mechanism whose essential parts are a lever and a weight. The requirement of a perfect dynamometer is that it shall not itself be a charge on the power—that is, that by its interposition the expenditure of driving force required shall not be sensibly increased. This property belongs to all that class in which the power of the motor acts directly with all its force to produce flexure in springs, while the springs, by their effort to recoil, transmit the force undiminished to the machine.

Prony Dynamometer.—A form of dynamometer for measuring the effect (horse-power) that a motive machine imparts to the transmitting shaft, called, after its inventor, the Prony dynamometer or friction brake,

is shown in Figure 5 (*pl.* 127). It consists of two friction blocks (E, F) and a lever (C) carrying on its outer end a scale (D). The friction blocks are screwed to the journal to be tested, and tightened by the screws G until the unweighted lever stands in a horizontal position. The shaft is now set in motion by the prime mover, the screws G are gradually tightened, and weights are placed at D until, with a horizontal lever, the shaft revolves with the desired velocity. From the amount of weights placed on the scale D and the number of revolutions indicated, the effect imparted to the shaft by the motor can easily be calculated. To prevent the lever from being whirled around in a circle by the friction of the shaft if the scale be not sufficiently weighted, the stationary studs I, I are provided; moreover, soapy water is poured through the funnel H on the circumference of the journal to prevent its running hot, and also to prevent the possible ignition of the braking-blocks by the frictional resistance.

The Balance Dynamometer (*figs.* 6, 7), an invention of Samuel Batchelder of Boston, is placed in the line of communication between the motor and the machinery to be moved; the power exerted on the machinery may be exactly measured by means of the steelyard and weight. There is also connected with it an index to show the number of revolutions of the drum for a given time, which, being observed together with the weight, gives the data for computing the number of pounds of static force exerted at the time on the dynamometer. The machine receives its power from the prime mover by a belt on the pulley A, and the power is transmitted to the machine (which is the subject of experiment) by a belt from the pulley B. The first pulley A and the bevel-wheel D are fast on the shaft C, which revolves in bearings I. The bevel-wheel F is connected with the pulley B by a sleeve K, which is capable of turning on the shaft C. The bevel-wheels DF are geared together by the bevel-wheels EE, which run on a cross shaft having a boss G, through which the main shaft passes freely. It is evident that if this cross shaft is not retained in its place by some adequate force, the motion of the bevel-wheel D will only cause the cross shaft to move round on the shaft C, and the wheels E will roll on the wheel F without communicating motion to it or to the pulley B; but if the wheels E and the cross shaft are held stationary, the motion of the pulley A will be communicated to the pulley B through the bevel-wheels, and the force there applied to retain the shaft G and the wheels E in place will indicate the power transmitted through the dynamometer. The amount of power is ascertained by means of a graduated scale-beam H, J, connected with the shaft of the wheels E by straps a. The weight M, fastened to the shorter arm of the graduated beam by a set-screw, affords a means of balancing the beam when the machine is at rest, and the weight W, like that of a common balance, when moved on the graduated arm of the lever, will indicate the strain on the belt. The number of pounds thus indicated, multiplied by the number of feet through which the belt moves per minute, will give the number of pounds raised one foot per minute; the prod-

uct, divided by 33,000, gives the horse-power expended in driving the machinery. (Contrivances for indicating the action of steam are considered in the sections on steam-boilers and steam-engines.)

Measurement of Speed: Anemometers.—For determining the velocity of the wind there are employed various devices called "anemometers." They consist for the most part of a "fly" or small wind-wheel and shaft that actuate a train of gearing which causes a pencil to trace a record of the velocity, as also the direction, of the wind on paper specially ruled for the purpose. In one form of the machine the recording paper is placed on a stationary cylinder about which the pencil is moved as the wind changes its direction; in a modified form the paper is slowly moved by clock-work.

Figure 8 (*pl.* 127) shows the anemometer adopted for United States Signal Service stations. It consists of four hemispherical copper cups mounted on radial arms at right angles to one another, with the planes of their faces vertical and facing the same way. The rods are fixed on a vertical axis turning in a tube and having at its lower extremity an endless screw placed in gear with a wheel that moves two concentrically-mounted dials which register the number of revolutions of the cups. The outer dial is graduated with one hundred and the inner dial with ninety-nine divisions. As both dials are moved by the same wheel, but in reverse directions, they will move forward at the same time, but the inner dial will complete one revolution and its zero will be one division beyond the zero of the outer dial when the latter has completed one revolution, the zeros of both dials coinciding at the time the instrument is set in motion. Thus the revolutions of the outer dial are recorded on the inner one. On the outer dial, at equidistant points representing one mile, are pins which depress a spring at the lower part of the dial and close an electric contact, by which the movement of the wind is electrically recorded on the cylinder of the apparatus shown in Figure 9 (*pl.* 127). The cylinder of the recording instrument is operated by clock-work, and has a rotary movement and a lateral movement in the line of its axis; the record is imprinted by means of a pencil on a paper diagram placed around the cylinder.

Tachometers.—Appliances for measuring the motion of machinery are variously known as tachometers, velocimeters, speed-recorders, speed-indicators, etc. The tachometer is a contrivance for indicating minute variations in the velocity of a machine. Some are purely automatic, while others, in conjunction with their mechanism, are operated by hand.

Speed-indicator.—Figure 4 is a device designed to register the speed of any rotating shaft, pulley, or mandrel. To ascertain the number of revolutions of a shaft in a given time, the point of the indicator is placed in the centre of the end of the shaft, and for each hundred revolutions the dial revolves once. Less than one hundred revolutions will be indicated by the pointer, which requires to be placed at the 100 mark before starting. By a device on the face of the dial, a person may feel with the end of the thumb how often it revolves without looking at the indicator, thus enabling the operator to keep correct time.

Train Speed-recorders.—For ascertaining and recording the speed of railway trains at any given instant special appliances have been devised. The Westinghouse railroad speed-indicator not only records the train speed, but also, by means of automatically-constructed diagrams, exhibits the fluctuations in the velocity caused by the application of the brakes. The registrations are made on a paper drawn similarly to that used at meteorological stations to record the velocity of the wind. The heights of the recording lines on the diagrams represent pressures on the accumulator of the speed-indicator, and these pressures are proportioned to the square of the speed.

Dynagraph.—A machine for recording the phenomena occurring to a train in travelling on a railway-track was invented by Professor P. H. Dudley and called a "dynagraph." The apparatus is placed in a car and uses fourteen diagram recording-pens. The track-inspection record is traced on a continuous roll of paper in a length of 100 feet wound upon a drum. The paper has various groups of rulings, and the tracings are made by glass tube-pens filled with eosine. The speed of the train is recorded by means of an electrical attachment with a chronometer clock. This attachment is so arranged as to break an electrical current every second, the current releasing an armature of an electro-magnet, with which one of the pens is connected. This moves the pen $\frac{1}{16}$ of an inch horizontally, and produces an indentation in the line which is drawn on the paper. The distance between the indentations indicates the space travelled over in one second. Another pen is so arranged as to make a similar record every ten seconds; still another pen can be used to record minutes. A pen is also so arranged that by an electrical connection it records each revolution of the driving-wheels; another records the mile-posts as they are passed, which is done by an assistant who touches an electrical key at each post. The alignment of the road—that is, the curves and straight lines—is recorded by a pen in a similar way. Next to this pen, and connected with a water-meter attached to the feed-pipe of the locomotive, is a pen which records the quantity of water consumed at different times and places. Still another pen is so arranged that an assistant on the locomotive records every shovelful of coal as it is put on the fire. The same pen has been used to record the time that black smoke escaped from the stack. A pen is also provided which records the distance run by the car, and another records the indications of an anemometer on the top of the car, while another pen records the surface of the track.

B. SPECIAL APPLIANCES.

Typewriting Machines.—The first patent for a typewriting machine was obtained in 1714 by Henry Mill of England. The apparatus is not described, except that it was a device to write in printed characters one letter at a time, one after another. After the lapse of more than one hundred and twenty-five years, an English patent was issued (1841) to Alexander Bain and Thomas Wright, entitled "A Machine to Print Intelligence at Distant Places." This was designed for what is now called a "printing telegraph." (See Vol V., p. 352.) The first American patent was issued in 1843 to Charles Thurber of Worcester, Massachusetts. Thurber's machine was slow and impracticable. In 1848, Fairbank was granted a patent for a machine, which consisted of several series or systems of vertical converging rods, each system being so adapted as to be pushed up and down vertically, like piston-rods, against a common impinging point. On the upper end of each rod was the desired type. This machine was designed for printing colors on cloth, but it is classed with typewriters. In 1849 a French patent was taken out by Pierre Foucault, a blind man in the Paris Institute for the Blind. This machine printed embossed letters for the blind, and proved a success. In 1850, Oliver T. Eddy of Baltimore, Maryland, received a patent-right, but no model of the invention can be found, nor was any machine produced. American patents were issued in 1852 and 1854, and three in 1856. Between 1856 and 1866 several other patents were issued, but none of these inventions proved to be of much practical value.

Remington Typewriter.—The first successful typewriter was invented and patented in 1868 by Christopher L. Sholes (1819–1890) of Milwaukee, Wisconsin. In 1866 he was engaged in developing a new machine for printing the numbers or folios on the leaves of blank-books after such books were bound. Upon a suggestion by Carlos Glidden for a machine to "write letters and words instead of figures," and the description in *London Engineering* of a machine called the "pterotype," which was invented by John Pratt of Centre, Alabama, but then residing in London, and which was designed to do just what Glidden had suggested, Sholes decided to try what could be done with the idea. Sholes invited Glidden to join in the effort, and subsequently, Samuel W. Soulé was invited to join the enterprise, and thus they became associated. Early in 1867, Sholes began work on the machine, and in September of the same year, with the help and suggestions of his associates, there was finished the first machine on which letters were written; but notwithstanding that it worked successfully, so far as to write rapidly and accurately, trial and experience demonstrated it to be far short of an acceptable writing-machine. After repeated experiments with one device after another, the invention developed, until in the beginning of 1873 it was thought to be sufficiently perfected to warrant its manufacture. The machine was consequently sent to the factory of the Remingtons at Ilion, under whose careful supervision

and the care of their skilled artisans improvement followed improvement until the apparatus embodied the first practical typewriter, which is now known as the "Remington" (*pl.* 128, *fig.* 1).

Construction and Operation.—The engraved types are on the ends of a series of steel bars, which are arranged in a circle, and so pivoted that they may vibrate on the pivots and all strike at the same point in the centre of and a little above the horizontal plane of the circle by depressing the key-levers from the key-board. Directly over the point where the types all strike an inked ribbon is so drawn that every type strikes it in delivering an impression; each time a key is struck the ribbon automatically moves a slight distance, so that every type may strike it in a fresh place. Above the inking ribbon is a carriage which moves horizontally from right to left, and carries the paper; the paper is arranged to go under a cylinder or roller which acts as a platen for the inking ribbon and type, so that every time a key is struck a type is thrown up against the inking ribbon and carries it against the cylindrical platen, where the type leaves its impression on the paper. A spring pulls constantly against the carriage, held by a ratchet or trip, which lets go every time a key is struck and catches again; in the interval the weight pulls the carriage and paper along the space of one letter. As the carriage nears the end of its travel an alarm-bell is struck to notify the operator; the carriage is then drawn back by a single motion of the hand to the initial point, and at the same time a ratchet and ratchet-wheel attached to the cylindrical platen are made to revolve the cylinder and move the paper the distance desired for a line-space; the lines can be regulated to be close together or wide apart. The machine has thirty-nine characters, which by suitable manipulation can be increased to eighty. The following are the principal ones: a b c d e f g h i j k l m n o p q r s t u v w x y z A B C D E F G H I J K L M N O P Q R S T U V W X Y Z & , ; : . ! ? " " r. ' ( ) — - $ 1 2 3 4 5 6 7 8 9, which are actuated by keys arranged in four "banks" or rows, as shown in the Figure. Each key has inscribed on it a letter or character; these correspond with the types on the type-bars, each one of which carries two types, capital and lower case, or other duplicate signs, the one behind the other. When a capital letter is to be printed the depression of a key shifts the position of the cylinder so as to bring the second type in contact with the ribbon. By striking the key containing the desired letter, the corresponding type strikes the paper on the cylinder and prints the letter. When the pressure of the finger is removed from the key the type drops away from the paper, the carriage is released, and, by the action of the main-spring, is drawn forward just the width of a letter; then another key is struck, and so on, forming words and sentences. The simplicity and speed of this operation are marvellous; an average writing speed of forty words per minute can easily be attained with practice, and expert writers have been able to reach a speed of from sixty to seventy words per minute.

The success of the Remington machine has led to the invention of a

number of other machines of more or less ingenious mechanism. These, however, may be divided into three general classes: (1) type-bar machines, such as the Caligraph, the National, etc.; (2) cylinder machines, represented by the Crandall and the Hammond; and (3) wheel machines, of which there are several forms. In the "cylinder" machine the letters and signs are on a cylinder having a lateral and rotary motion produced by the striking of a key, which brings the proper type to the common printing point. An advantage claimed for this machine over the type-bar is that it is a variable spacer—that is, it gives more space to wide letters (m, w) than to narrow letters (i, t, l); another advantage is, that the cylinder having one style of type can be removed and a cylinder having another style of type can be substituted, so that many kinds of type can be employed in the same machine. The wheel machines are of simple construction. The letters and signs are placed on the periphery of a wheel whose rotation brings any desired letter into position for printing. The machine has a dial-index and pointer to indicate the type which is in position.

Type-setting Machines.—The problem of setting type by machinery has resisted nearly every effort at solution. The hand compositor of the present time employs precisely the same methods that Gutenberg used at Strasburg four centuries ago. Experiments with devices for saving time and labor at the "case" date back many years. The inventions of Mitchel, Delcambre, Fraser, Alden, and others were designed merely to duplicate by machinery the motions of the compositor's hands, but they could not stand the test of practical work. Perhaps the best of this class of machines were those of G. A. Burr; their results were fairly satisfactory, but they had certain defects which were fatal obstacles to success. In 1884, Ottmar Mergenthaler of Baltimore, Maryland, a native of Würtemberg, Germany, invented a type-setting machine almost human in its action. Its conception, however, was primarily due to James A. Clephane, a Washington stenographer, who had for years made writing- and printing-machines a study. In 1876, Mr. Clephane employed an engineering firm, of which Mr. Mergenthaler was a member, to work from drawings by a Western inventor, and in pursuance of this Mr. Mergenthaler showed a singular aptitude for this kind of work. He began to experiment by employing various methods of casting type-bars from matrices made by indentations in soft material, and he soon improved upon the crude device originally submitted. His first idea was to form a rotary machine with keys for impressing female dies in a continuous strip of heavy paper; this was superseded by a machine controlling a series of sliding bars bearing on their edges all the characters and spaces; a key mechanism moved these bars endwise so as to bring a selected character on any bar in a line with a previously selected character, and thus to form a matrix of a complete line for casting. In 1880 an entire change of system was made, and in 1884 the machine was completed whose perfected form is known as the "Linotype."

The Linotype (*pl.* 128, *fig.* 2) is in appearance somewhat like an upright piano. It is about 5 feet long, 5 feet high, and 3 feet broad. As is shown by the Figure, the most conspicuous objects, supported by the heavy iron base, are a typewriter key-board and a series of vertical flattened tubes. Each of these tubes or magazines contains a number of short strips of brass, having the mould for a particular character stamped in the farther edge. The bottom strip or "matrix" in each tube rests in a slot at the end of the corresponding key; and when this key is depressed, the matrix at once drops in an upright position into a groove or channel sloping above the key-board from right to left. A powerful air-blast instantly forces the matrix along a wire, which maintains it in its upright position to the lower end of the groove, and here two metallic fingers, working automatically, push it out into full view upon a horizontal slide; and as it is marked on the outer edge with the letter it represents, the operator can correct his work as he goes along. When all the matrices of a word are assembled on the slide, a touch on a particular key brings down a long, thin, wedge-shaped strip or "space-band." The thicker end of this wedge hangs below the matrices, just over a metal plate, so that when the line is finished the automatic raising of this plate will push the space-bands upward through the line until the different words are all equally divided, and thus the nice process of "justification" is accomplished at a single stroke.

The first step is now finished. The line is ready to be cast. But the operator simply moves a lever and goes on with his work at the keys, leaving the machine to do the rest; and it does it quickly and well. As the lever moves, the space-bands spread the words, a pair of clamps seize the line of matrices, remove them from the slide, and press them against the face of a vertical disc. Extending horizontally through this disc is a narrow opening or slot of the exact length of the required type-bar. Behind it a small gas-furnace keeps a potful of type-metal constantly at liquid heat; and while the moulded edges of the matrices are held against the disc, an automatic force-pump throws out a jet of molten metal through the slot. In an instant a block is formed of the size and shape of an ordinary line of types, bearing on its face in relief the letters corresponding to the line of matrices. The disc then makes half a turn, the bar meets a pair of automatic knives which trim it square, and the next moment it is pushed out solid, but still warm, at the bottom of a galley standing on end against the machine at the operator's left.

But now a series of even more ingenious operations is performed. Each of the matrices which have just been used must be restored to the tube from which it originally came, and in effecting this the machine displays an almost more than human intelligence. An operator intrusted to perform such a task by hand would first pick out the different sorts, then carefully compare them with the tubes, and finally use dexterity in placing them where they belonged. Not so the machine: as soon as a line is cast it simply withdraws the matrices from their position against the disc and lifts them by automatic carriers to the top of the machine. Here they

encounter a sort of endless railroad or belt fitted with hanging loops, which catch them up and travel with them from left to right above the tops of the tubes.

The tops of the matrices are cut in the shape of a V, the inner edges of this V being notched in such a manner that all the matrices of the same character are alike, and different from those of any other. As the belt moves along, these V's closely hug a stationary bar placed between the loops and fitted with an arrangement of fine ridges, which differ over every tube. These ridges correspond with the notches in the different V's in such a way that when a matrix is brought exactly above the tube to which it belongs, it no longer engages any ridges on the bar, the loop ceases to sustain it, and it falls at once into place, ready to be used again. To guard against possible mishaps, the distributing-bar is connected with wires from a battery, by means of which the premature dropping of a matrix closes an electric circuit and stops the carrier-belt.

The capacity of the machine in the hands of a competent operator is from 3000 to 5000 ems per hour, and six weeks are generally sufficient for a person of average intelligence to learn to attain this speed.

Mechanical Talking Machines.—For more than a century inventors have directed their ingenuity to the construction of a machine capable of imitating the human voice, notwithstanding the fact that such a machine would serve no practical purpose even if it could be perfected. Wolfgang von Kempelen, who invented the so-called "automatic chess-player," devised a talking head in which wind-tubes and vibrating reeds were set in motion by means of a bellows placed in the bust of the figure. The capacity of the machine was limited, but words and sentences were automatically enunciated without the use of keys or the intervention of an operator. Parts of the mechanism imitated the movements and action of the human mouth—lips, teeth, tongue, etc. A later effort was made by Faber, an ingenious Frenchman, who invented a talking-machine which consisted essentially of three parts: (1) the wind-producing apparatus, simply a bellows; (2) the sound-making arrangement or larynx, a tube so constructed that, within certain limits, a difference of tone could be produced; and (3) the articulating system, which included devices for sounding the vowels and consonants and for producing the nasal sounds. The vowels were sounded by the passage of air through differently-shaped openings in diaphragms placed successively in the current of air by means of levers actuated by the operator's fingers, and the consonants were produced by pieces whose action was analogous to that of the lips, the teeth, and the tongue. A special cavity produced the nasal sounds. Fourteen keys, very ingeniously disposed, put in motion these imitation organs of speech in such a way as to render the necessary intensity in action and variations in sequence of parts for pronouncing syllables. The language of the machine, while monotonous and imperfect, was sufficiently clear to make the words enunciated easily understood.

The Calculating-machine (*pl.* 128, *fig.* 4) is designed to assist in all kinds

of computation where multiplication and division form material parts of the work. This instrument, which is about 7 inches in height and 5½ by 13 inches on its base, does its work by untiring mechanism in an exact and automatic manner, and gives its results in plain figures. By its use the labor usually required of the brain is transferred to the hand, and time is saved on most descriptions of work. The machine has the advantage over common logarithms in point of time, ease, and accuracy. It is much easier and quicker to work with natural sines, tangents, etc., and natural numbers, upon this machine, than to use the common logarithmic method.

Simonds's Metal-rolling Machine (*pl.* 128, *fig.* 3) has for its object the economical and accurate production, from ductile or malleable metal, of articles of circular, or approximately circular, form, other than simple cylinders. The means resorted to for attaining such results consist in swaging-dies which move in opposite directions, and whose surfaces approach each other and first roll the ductile metal into form and afterward produce by continued rolling a finished surface.

The important features which distinguish this invention from other devices having a like object in view are the drawing of the metal of a rod in the direction of its axis, thereby reducing its diameter in whole or in part, instead of "upsetting" or shortening the metal and thickening portions to a greater diameter than that of the rod, and a non-requiring of any attempt to finish the surface until the metal has been shaped in the form desired for the complete article.

The machine consists of two reciprocating tables, which slide vertically in guides simultaneously and with equal velocities, but in opposite directions. These tables are propelled by a train of toothed gearing, which, operated by two pulleys turning in reverse directions, engages with racks and pinions. The pulleys are alternately engaged with the gearing by a coupling or clutch actuated by a shifter participating in the motion of the gearing propelling one of the slides. One of the guides, with its sliding table, may be so adjusted as to distance from the other that the changes required by the diameter of the work may be made.

The dies, which are fixed to the inner sides of the slides, are so formed that as one descends and the other ascends the space between them diminishes. A heated bar of metal being placed between them is rolled, while the position of its axis is not changed. The working faces of the dies are so inclined, as to the direction of their motion, as to draw the metal lengthwise in the direction of the axis of the bar, whose rotation is enforced by teeth which are formed in the prominent parts of the dies, and which indent and turn the metal as two oppositely-moving racks would turn a pinion placed between them. In no part of the operation is attempted the compression or shortening of the metallic bar in the direction of its axis.

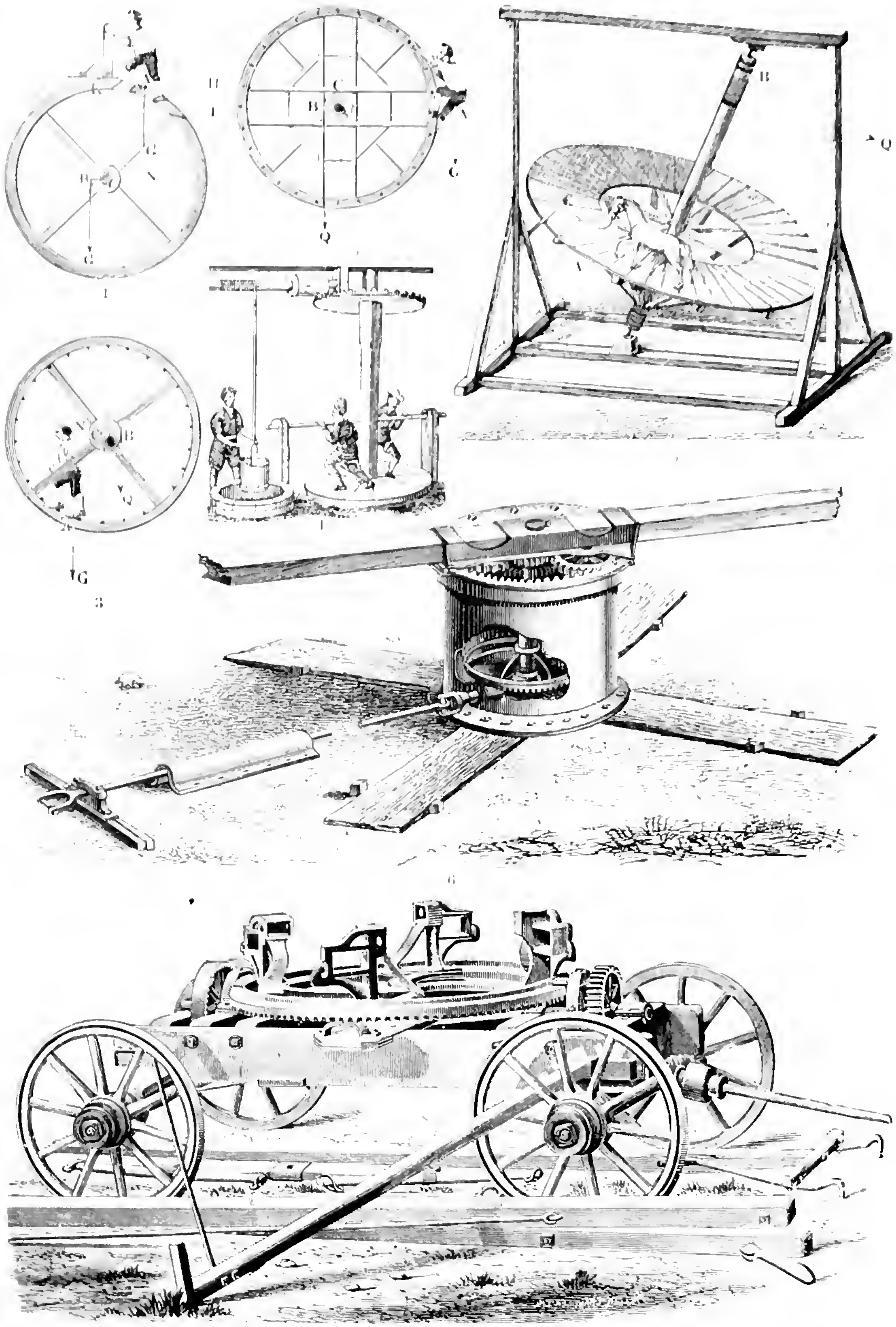
The reduction in diameter is so gradual that material of a reasonable degree of strength and homogeneousness is never severed at the centre by

being flattened and by moving in opposite directions, but instead there is an extension in the direction of the axis. This effect is produced by the gradual inclination of the dies toward each other, which inclination is attended with a relatively rapid divergence of their prominences or ridges and intervening cavities. This configuration of the dies proceeds to the point where all parts of the material are reduced to the proper diameter. In the rest of its length the ridges or working surfaces of the dies are parallel and finish or smooth the surface of the article.

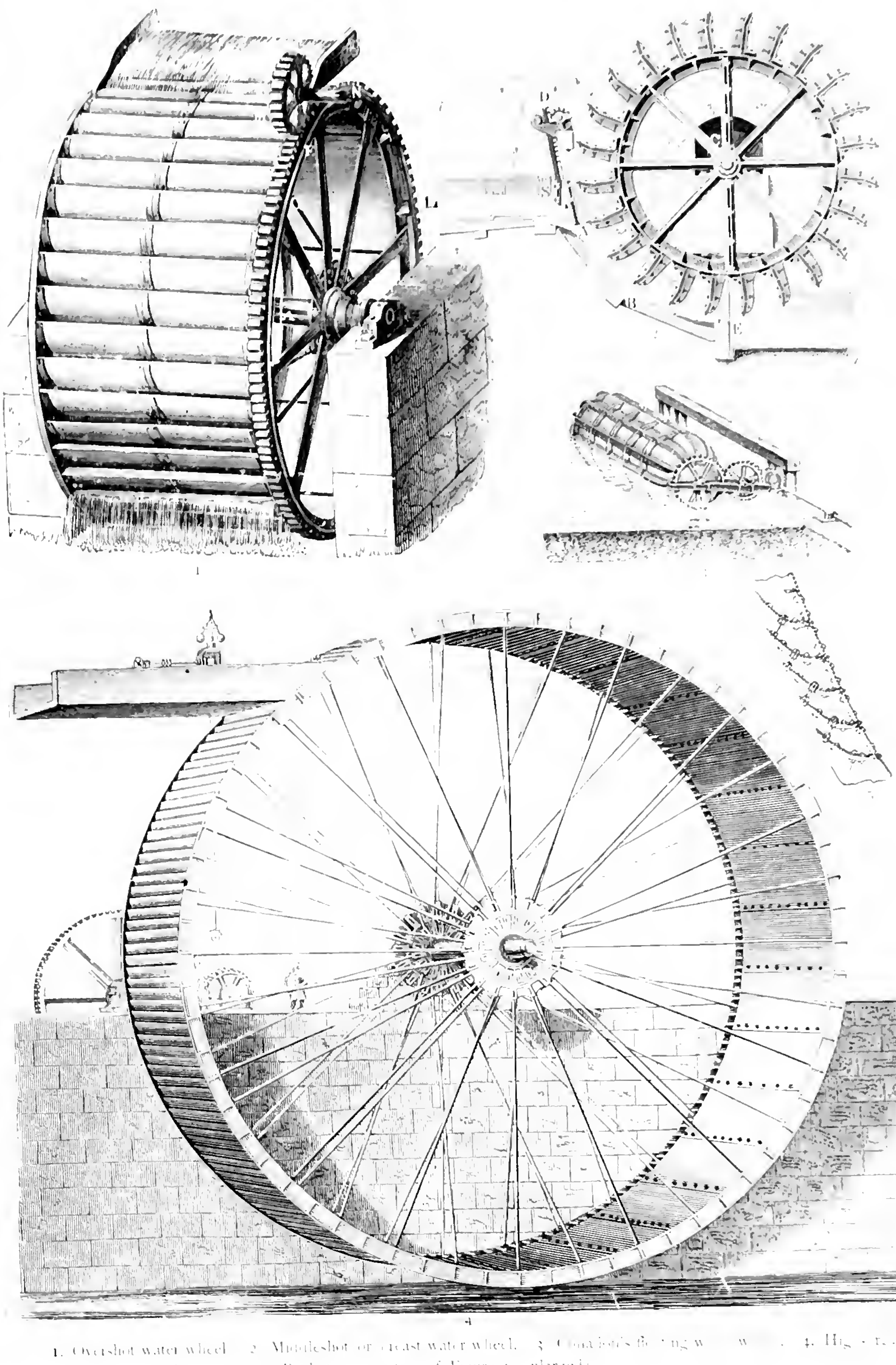
Automatic Vending Apparatus.—References have been made in the present volume to instances of mechanical *reinventions.* A curious example of a modern invention, whose prototype appears to have been known and employed before the Christian era, is the "drop-a-nickel-in-the-slot" machine. In the sixteenth century there appeared a manuscript by Hero entitled *Spiritalia seu Pneumatica*, which contained an exposure of the many deceptions practised by the Egyptian hierarchy. In this work is described a device for automatically dispensing to the worshippers, on their entrance to the temple, the lustral or purifying water which was a source of revenue to the Egyptian priests. Figure 5 shows, partly in section, this apparatus, whose construction and operation, according to Hero's description, were as follows: The vase-shaped vessel was entirely closed with the exception of a slit at the top for the introduction of the necessary coins, which were five *drachmæ* (about seventy-five cents), and no less amount would produce a drop of the lustral water. The water was contained in a cylindrical vessel, to the bottom of which a small tube was attached and continued through the side of the vase for the discharge of the liquid. The inner end of the tube formed the seat of a valve whose plug was fixed on the lower end of a vertical rod. The upper end of the rod was connected by a pin to one end of a horizontal vibrating lever, whose other end was spread out in the form of a flat dish for the reception of the coins dropped through the slit. The weight of the rod kept the valve closed, and no liquid could escape. When the required coins were dropped through the "slot" upon the dished end of the lever, the lever was depressed and raised the rod of the valve, which opened and permitted a portion of the water to flow out through the discharge tube. The quantity escaping, however, was small, not only because the bore of the tube was small, but also because the valve was open but for a moment, for as the lever became inclined from its horizontal position the pieces of money slid off, and the dropping of the valve-rod quickly stopped the efflux of the water.

The idea of the Egyptian apparatus is embodied in the numerous patented inventions by which a predetermined quantity of fluid is released or by which packages of confectionery or of other articles of merchandise are presented upon depositing a nickel in the slot. Figures 6 and 7 exhibit a typical example of the merchandise vending-apparatus, whose operation is as follows: When a coin is dropped through the coin-slot *c*, it passes through the slot *c'* of the delivery-slide *C* into the upper trans-

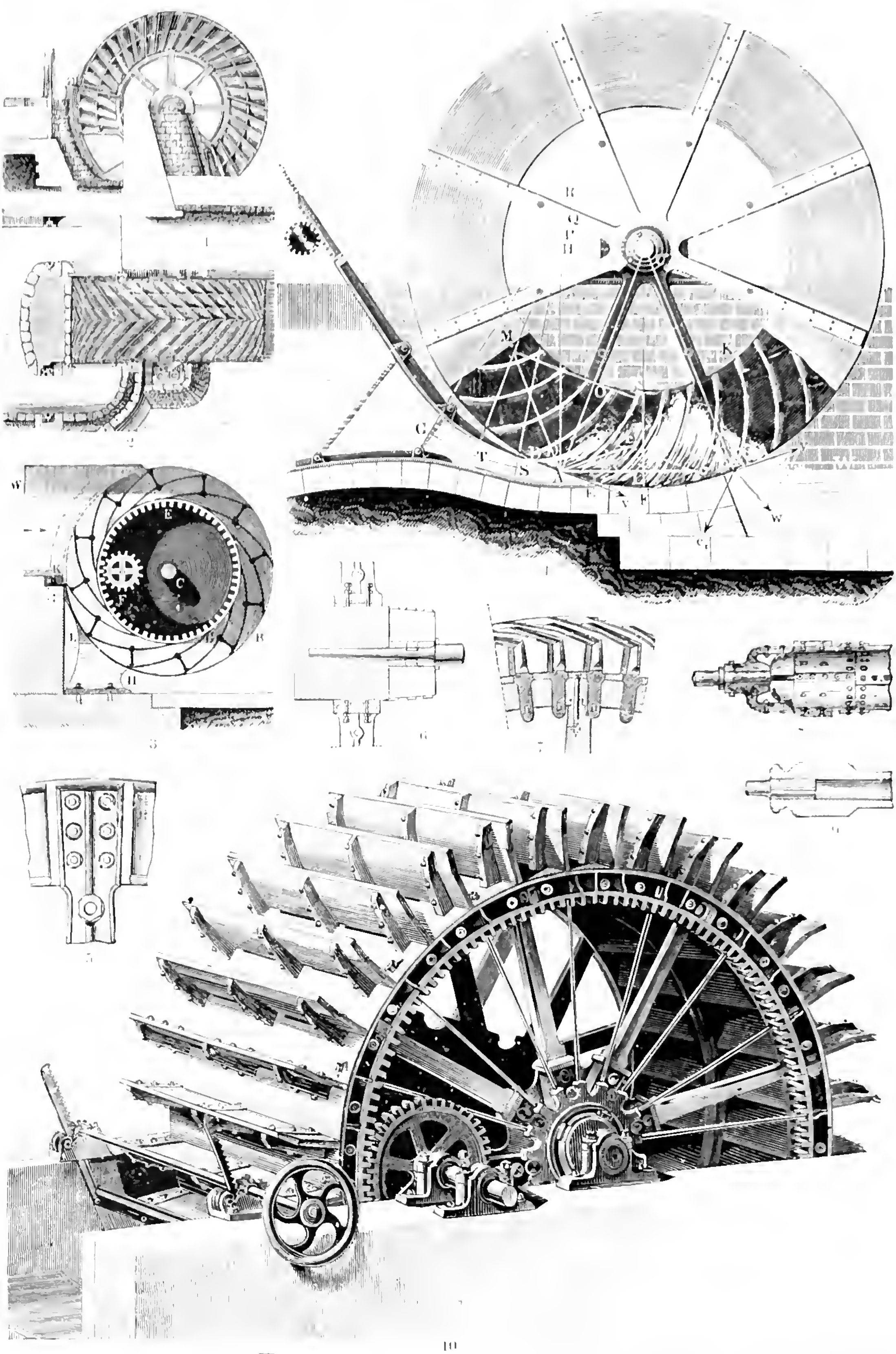
verse part of the coin-chute E, then by gravity downward so as to push the hinged gate E' aside, and to roll with considerable momentum into the lower vertical part of the coin-chute, where it strikes against the wire shank of the locking-lever F, moving the latter backward and releasing the latch F from the lug f of the delivery-slide C, as shown by dotted lines in Figure 6, whereby the delivery-slide can be drawn forward so as to deliver a piece of confectionery (*fig.* 7). As soon as the delivery-slide is moved forward, the coin, which has been retained in the lower end of the coin-chute by the abutment on the rear wall of the case, is dropped to the bottom of the case by reason of the forward movement of the coin-chute. The twisted shape of the chute at E' causes the coin to pass from a vertical transverse position to a vertical position parallel with the side walls of the casing; thus tampering with the apparatus is prevented, and the coin when once dropped cannot be removed. The twisted form of the chute serves also to retard a metal disc of less weight than the coin required for releasing the locking-latch F, as the disc arrives at the lower end of the chute with a momentum which is not sufficient to overcome the inertia of the locking-lever and to release it from the lug f' of the delivery-slide. The main part of the delivery-slide C extends through an opening in the front wall of the lower part of the casing A' to the outside, and is provided with a knob by which the slide C is pulled outward whenever the locking mechanism is released.



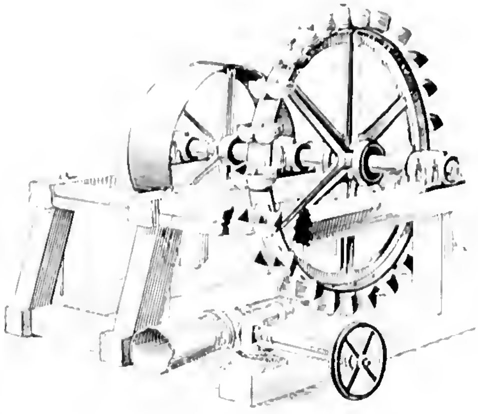
1. Tread-wheel. 2. Step-wheel. 3. Tram-wheel. 4. Water-raising horizontal tread-wheel (from Agricola). 5. Horse tread-plane. 6. Barrett's portable horse-power. 7. American mounted horse-power.



1. Overshot water-wheel. 2. Middleshot or breast water-wheel. 3. Colladon's floating water-wheel. 4. High-breast water-wheel (30 feet diameter). 5. Bucket-construction of Figure 4 (enlarged).



1. Elevation, 2. Plan, of Sagebien's water-wheel. 3. Zuppinger's water-wheel. 4. [illegible] water-wheel [illegible] system. 5. Arm and rim connection of a cast-iron water-wheel. 6. Bearing of [illegible] shaft. 7. [illegible] of an overshot wheel with ventilation. 8. Plate-metal shaft and bearing. 9. Cast-iron shaft and bearing. 10. [illegible] wheel with overflow sluice-gate.



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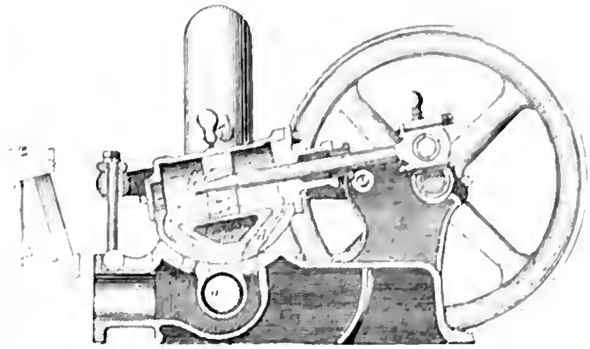

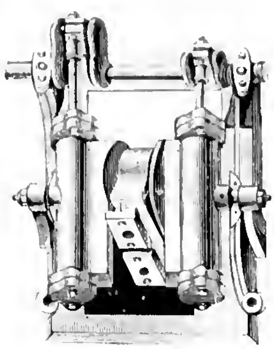

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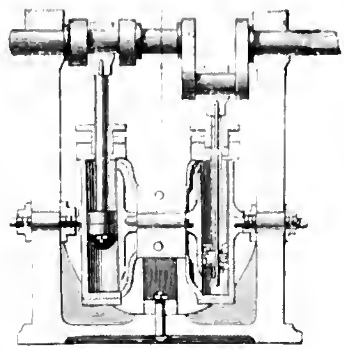

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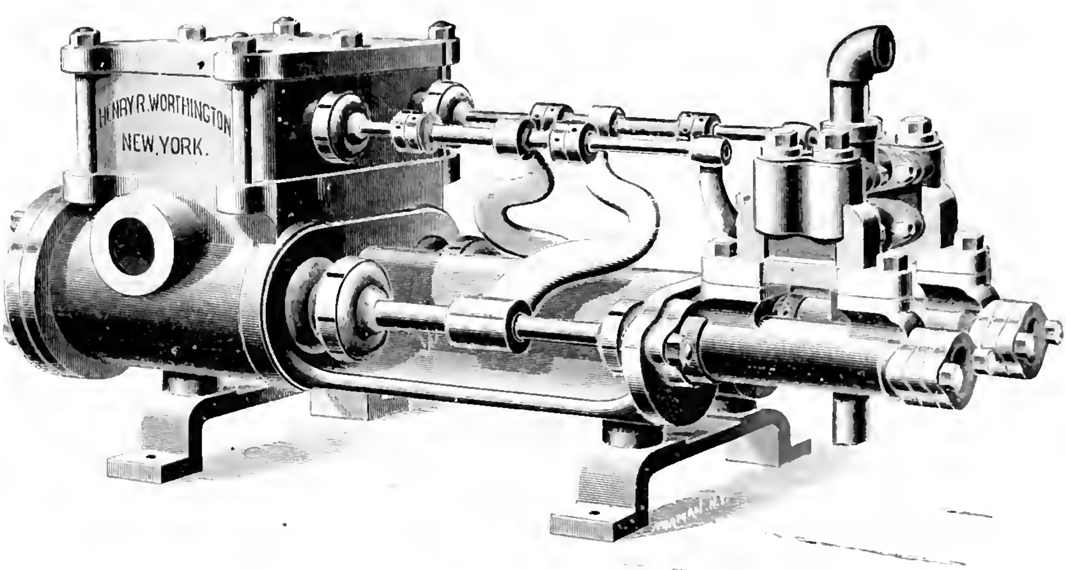
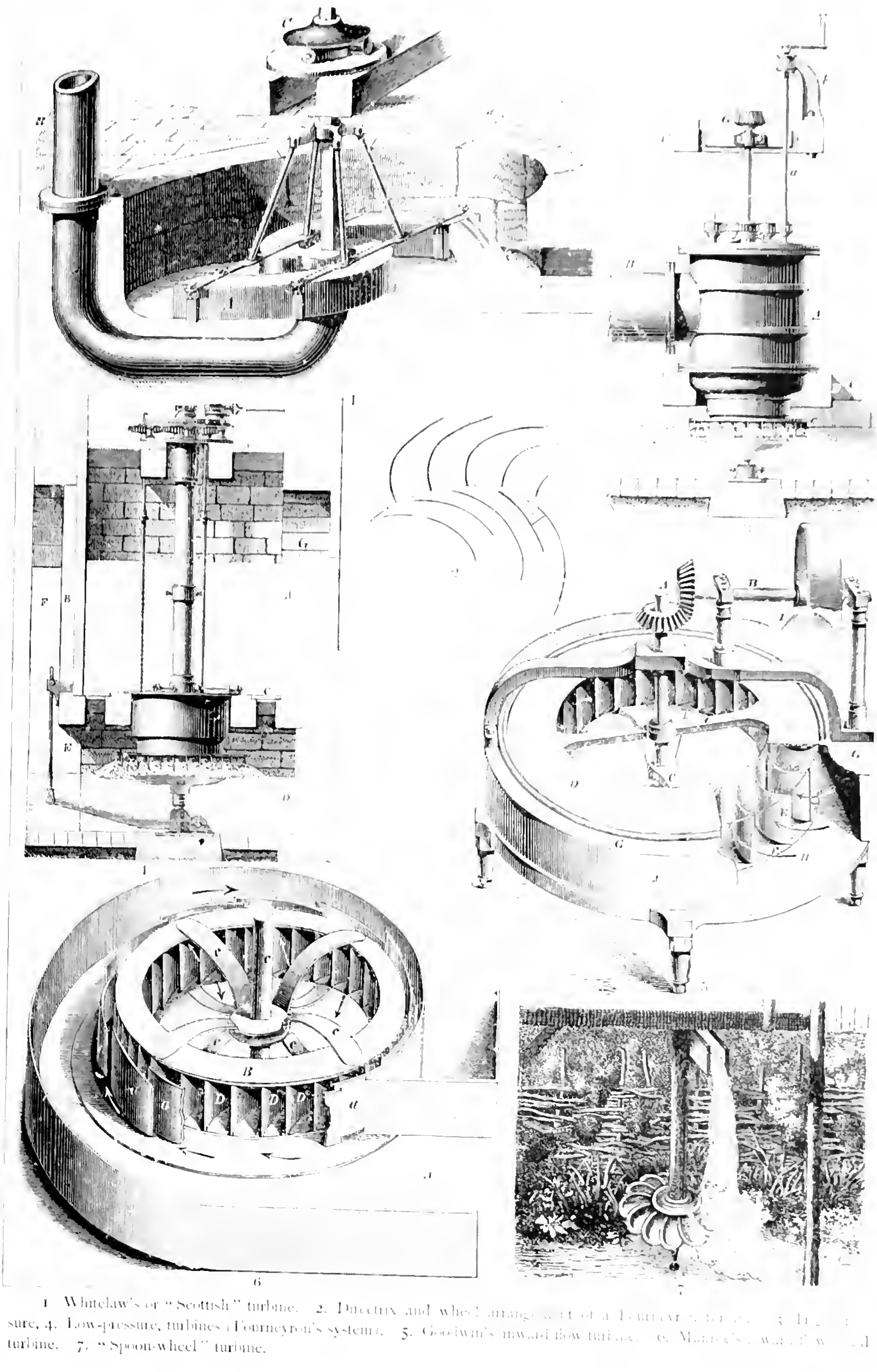
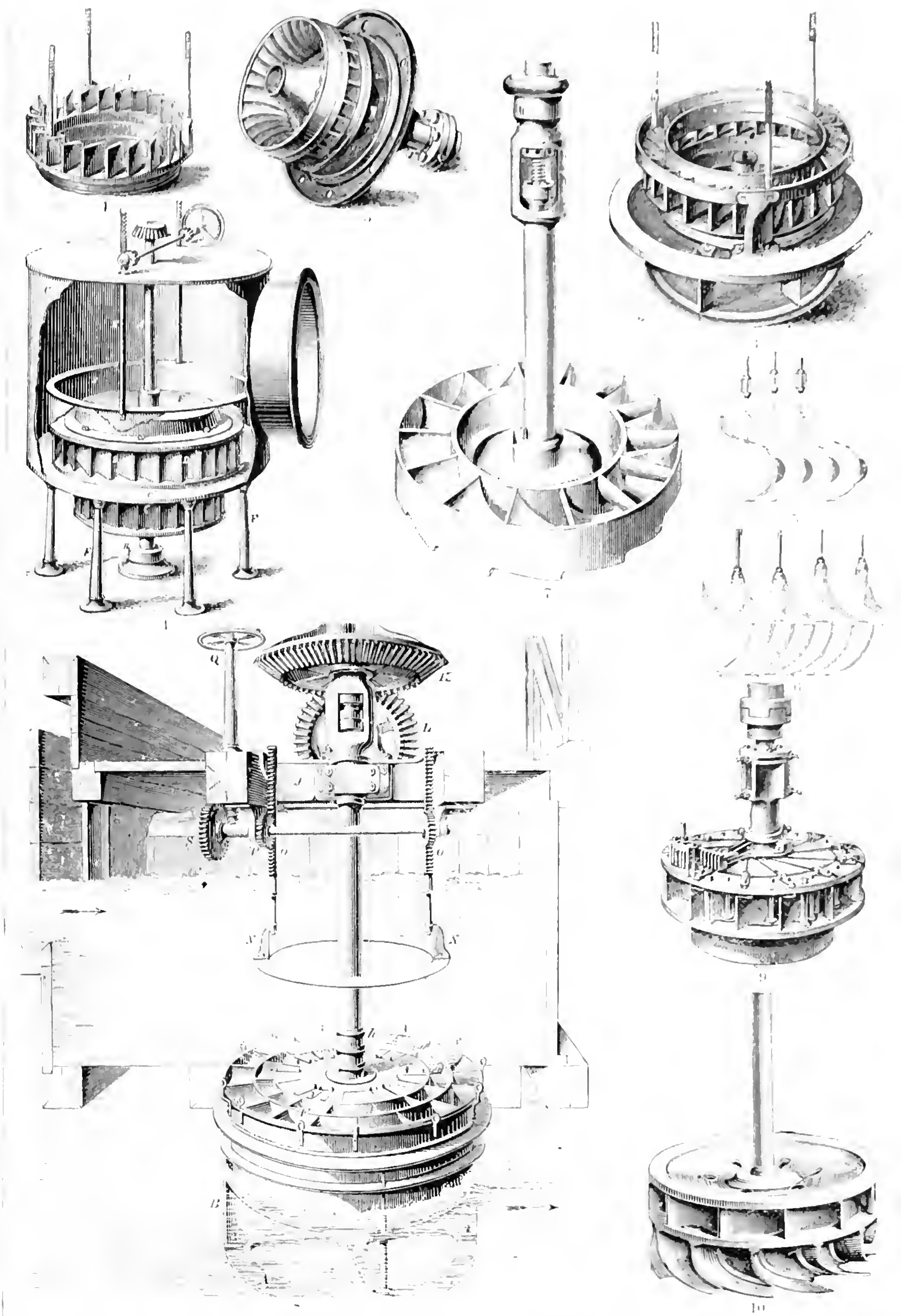


6

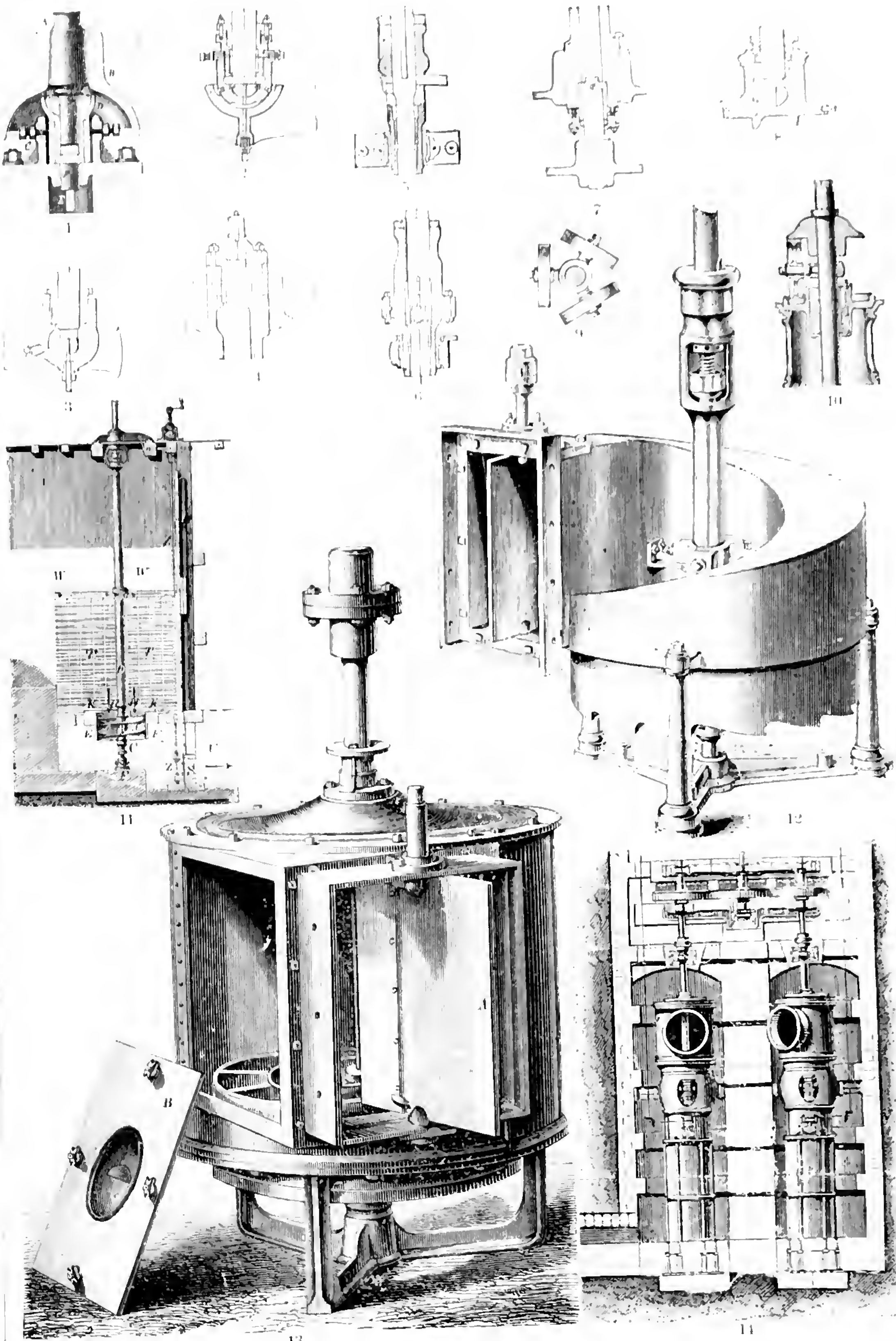
1. Pelton water wheel. 2. Schmid's oscillating-cylinder hydraulic engine (Swiss). 3, 4. Ramsbottom's water-pressure engine. 5. Water motor (Backus Water motor Co., Newark, N. J.). 6. Worthington water meter (Henry R. Worthington, New York).



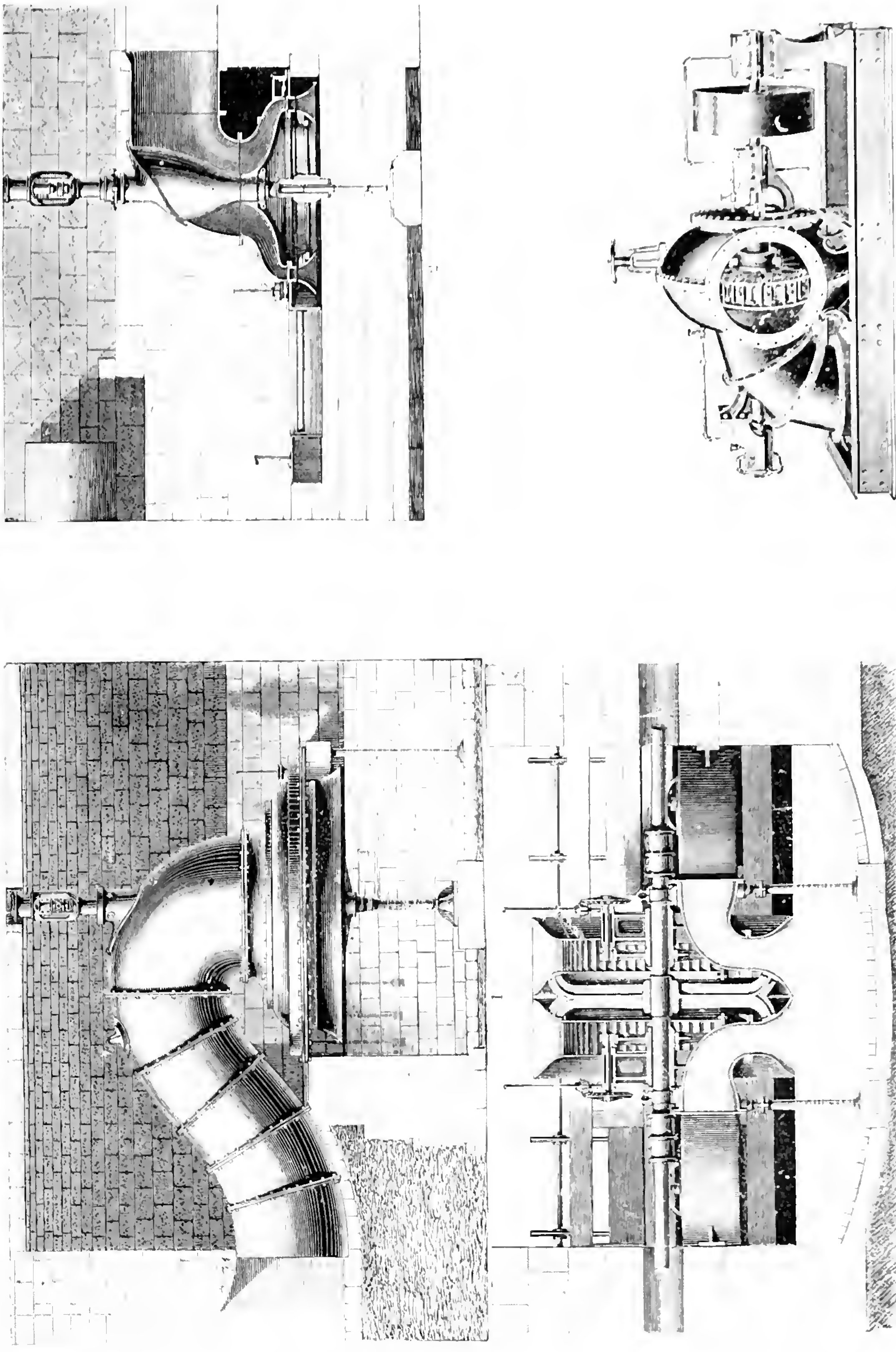
1. Whitelaw's or "Scottish" turbine. 2. Director and wheel arrange[illegible] of a [illegible] turbine. 3. H[illegible]-[illegible]sure, 4. Low-pressure, turbines (Fourneyron's system). 5. Goodwin's inward flow turbine. 6. [illegible] turbine. 7. "Spoon-wheel" turbine.



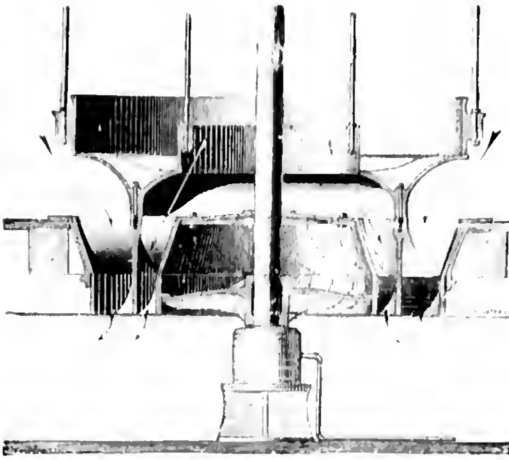
1. Guides, 2. Revolving-wheel, 3. Wheel completed, of Howd's iron turb[illegible] 4. Stanley's [illegible] 5. [illegible] wheel arrangement of a Girard turbine. 6. Paddle wheel arrangement of a H[illegible] [illegible]lonval tur[illegible] 7. W[illegible] "helix" turbine. 8. Decker's turbine. 9. Perspective, 10. Wheel, of a double turbine [illegible] James A. [illegible] New Y[illegible]



1–10. Various forms of pivot bearings of turbines. 11. Screw turbine. 12. Stevenson's helix turbine. 13. Watt's turbine. 14. Henschel-Jonval high-pressure turbine.



1. Girard's siphon turbine. 2. Girard's hydropneumatic turbine. 3. Girard's tangential double wheel ter... [illegible] New York.



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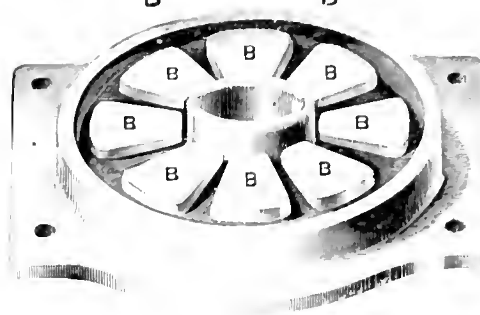

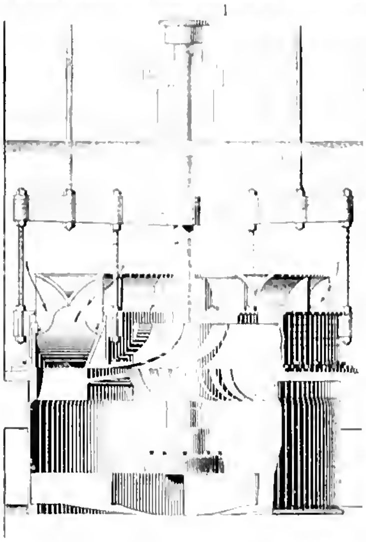

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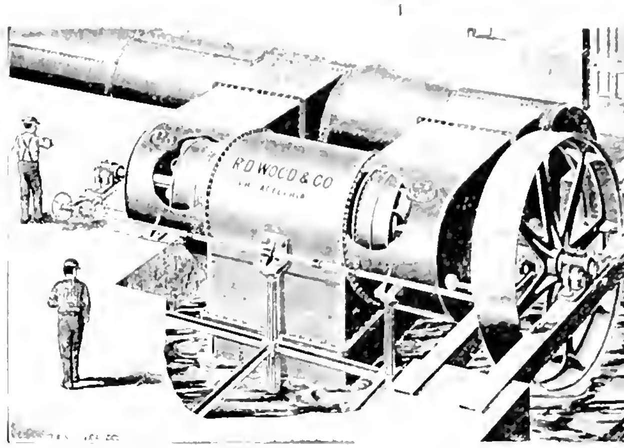

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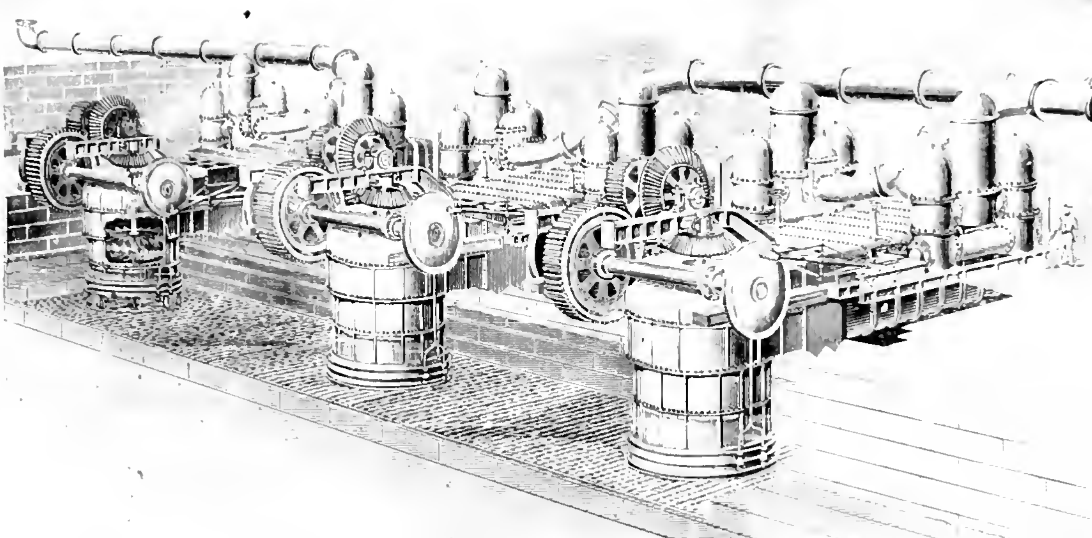

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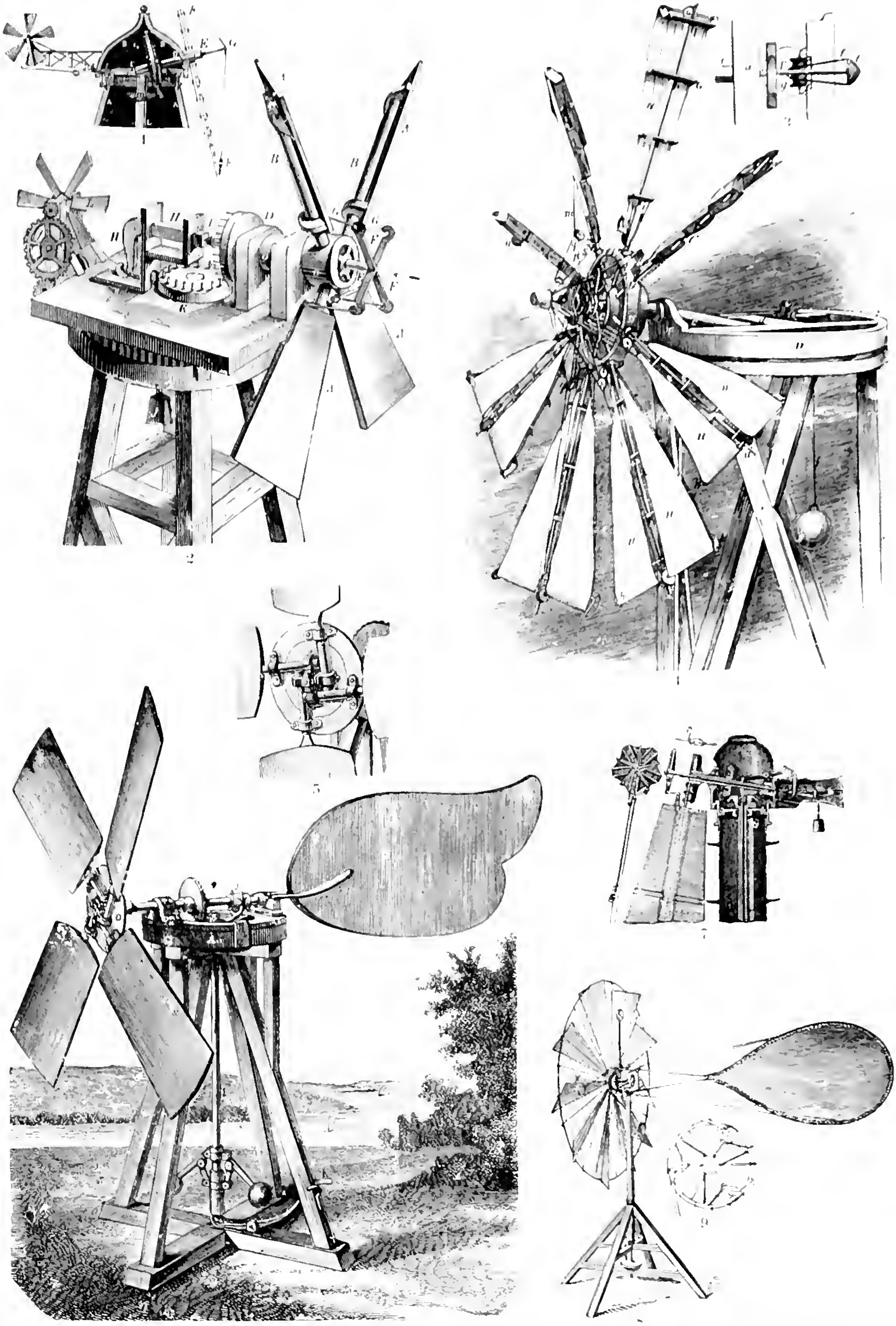
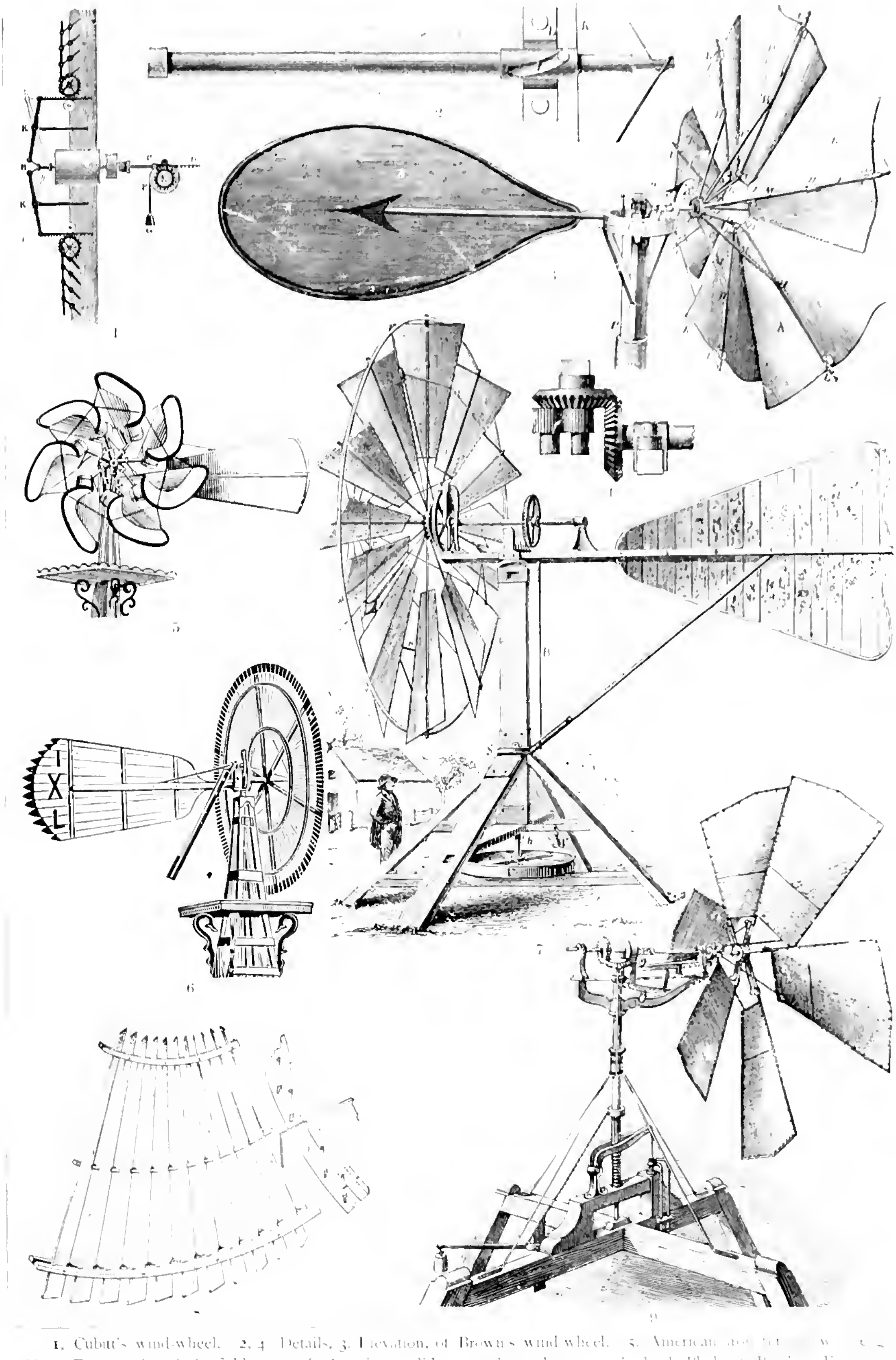
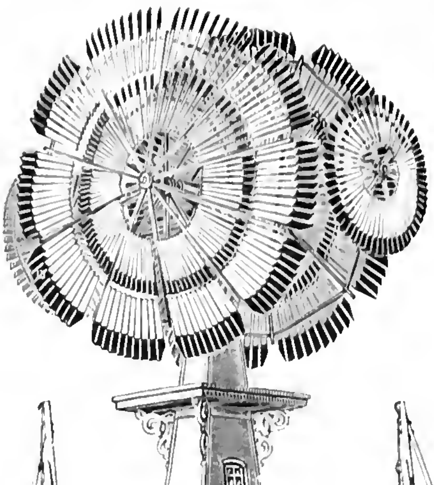
1. Geyelin's duplex Jonval turbine, 2. Geyelin's plain Jonval turbine, 3. Vert[illegible] 4. [illegible] suspension box, 5. Double horizontal 200 horse-power turbine without gearing, 6. Turbines [illegible] Philadelphia (R. D. Wood & Co., Philadelphia)



1. Cap of a tower windmill. 2. Brewster's wind-wheel. 3 Detail. 4 Perspective, of Wittig's wind-wheel. 5 Detail. 6. Perspective, of Trall's wind wheel. 7. Kirchweger's wind wheel. 8. Perspective, 9. Detail, of Johnson's wind-wheel.



1. Cubitt's wind-wheel. 2, 4. Details, 3. Elevation, of Brown's wind-wheel. 5. American [illegible] wind-wheel (Mast, Foos & Co., Springfield, O.). 6. American solid-vane self-regulating wind-wheel (Phelps & Bigelow, Kalamazoo, Mich.). 7. Dr. Frank's wind-wheel. 8. Double-rim twist slat arrangement of a solid vane wind-wheel (Phelps & Bigelow). 9. Lempcke's wind-wheel.



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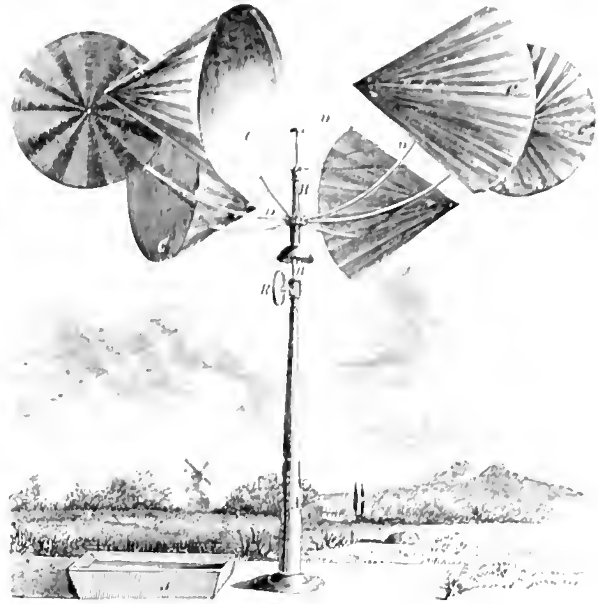

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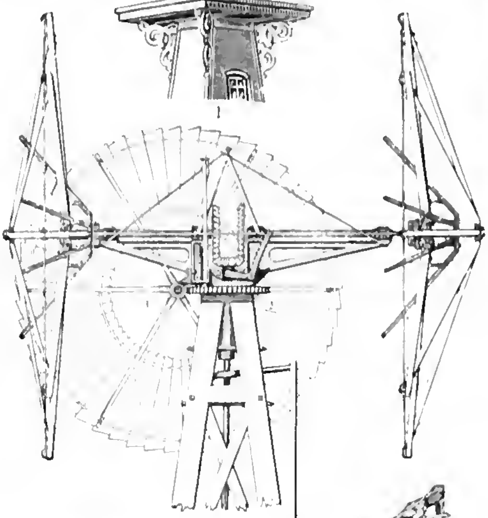

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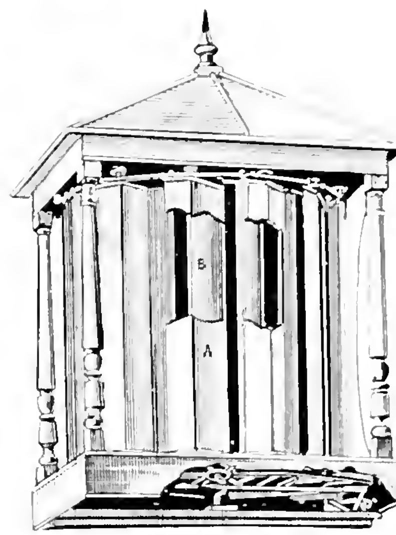

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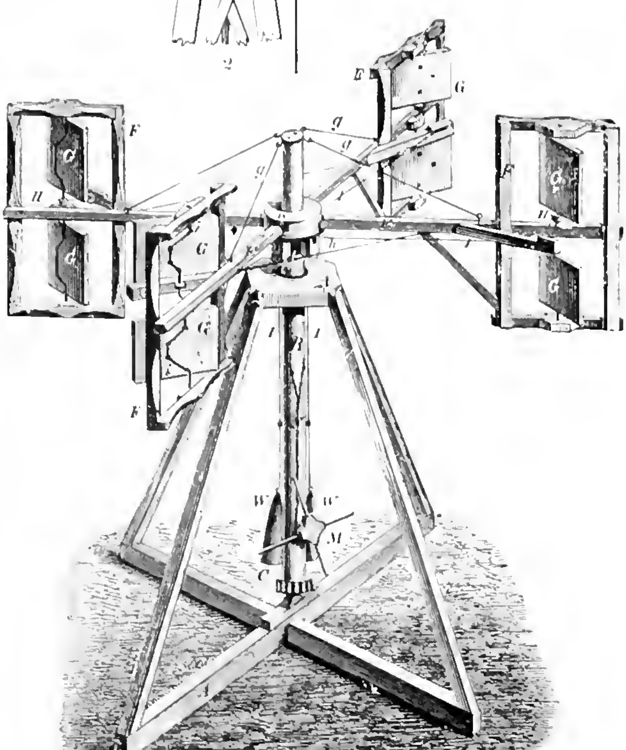

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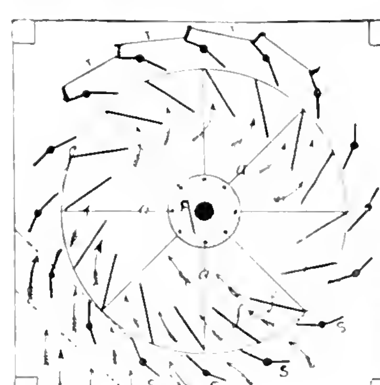

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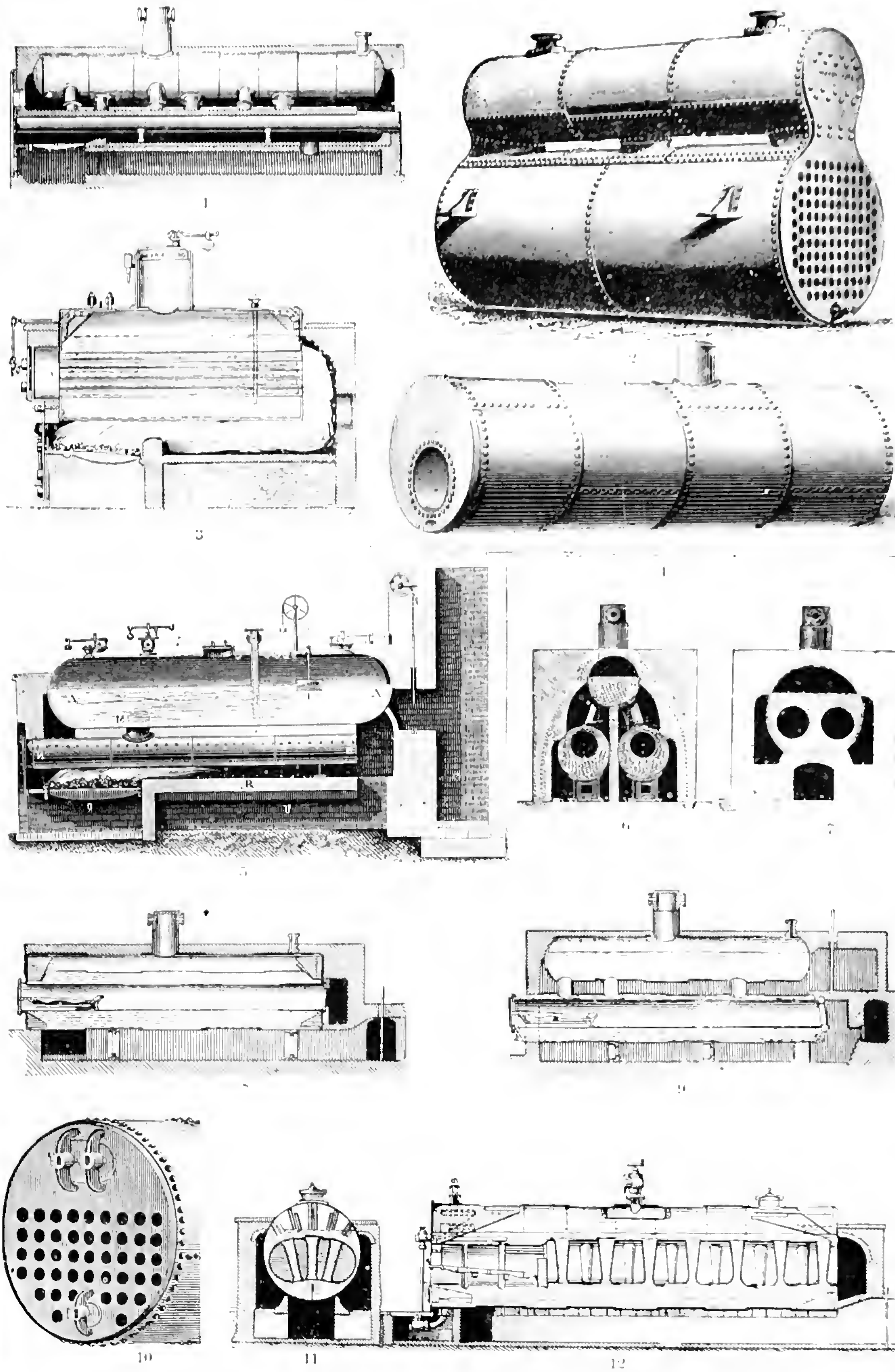
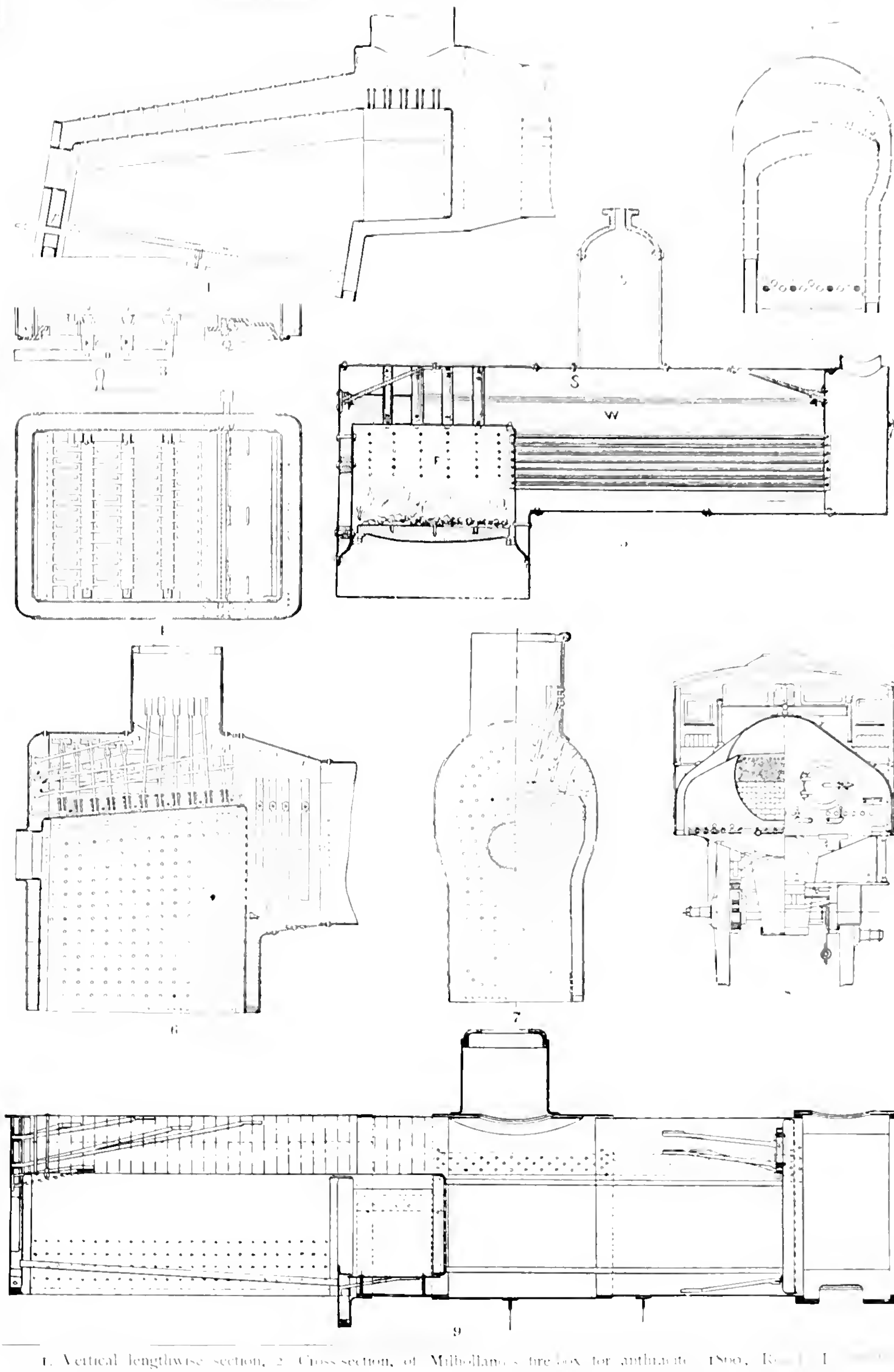
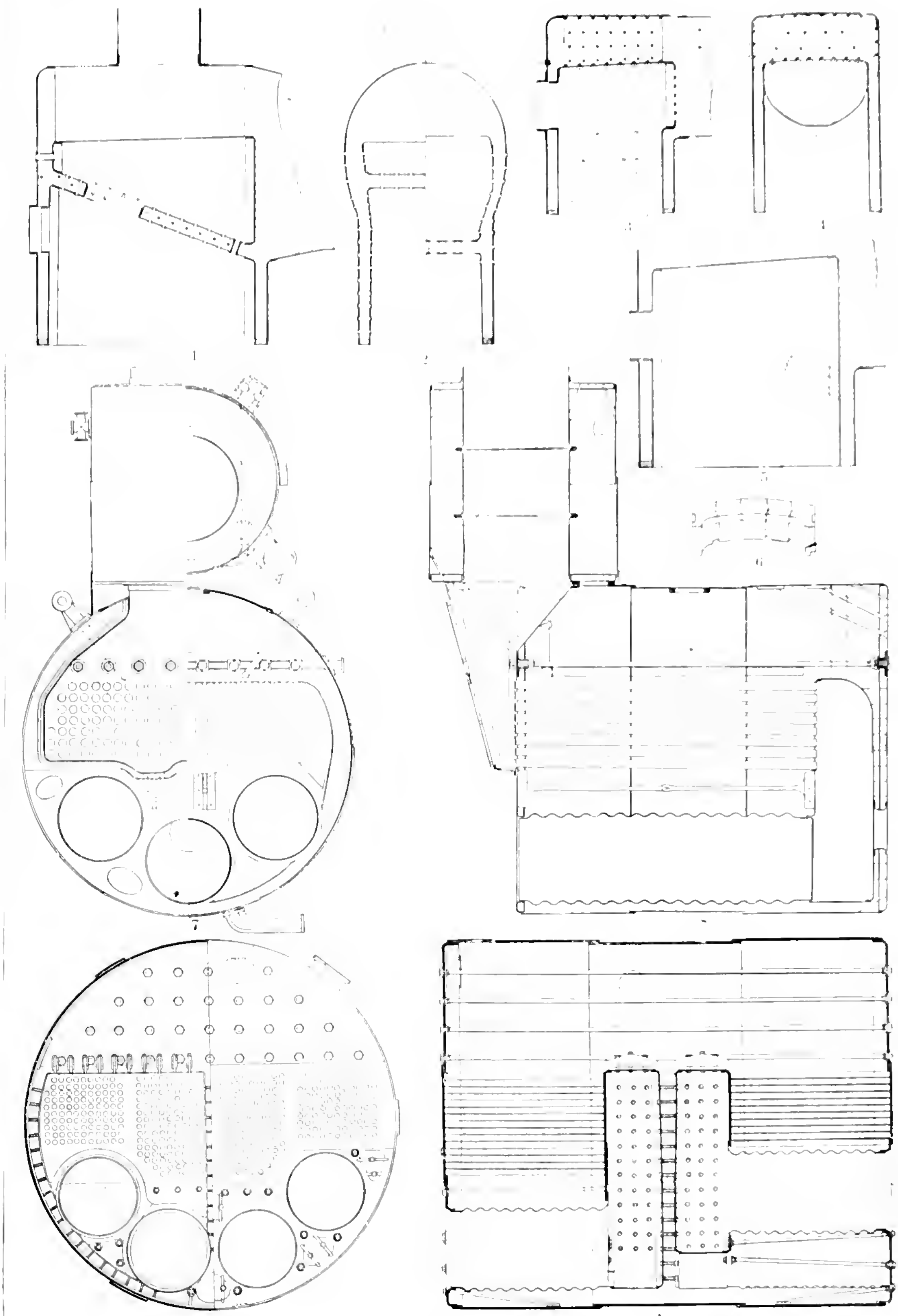
1. Perspective, 2. Details of construction, of a double wind-wheel (Challenge Wind-mill and Feed-mill Co., Batavia, Ill.). 3. Goodwin-Hawkins' horizontal wind-wheel. 4. Field's horizontal wind-wheel. 5. Elevation, 6. Plan, of an American horizontal wind turbine-wheel.



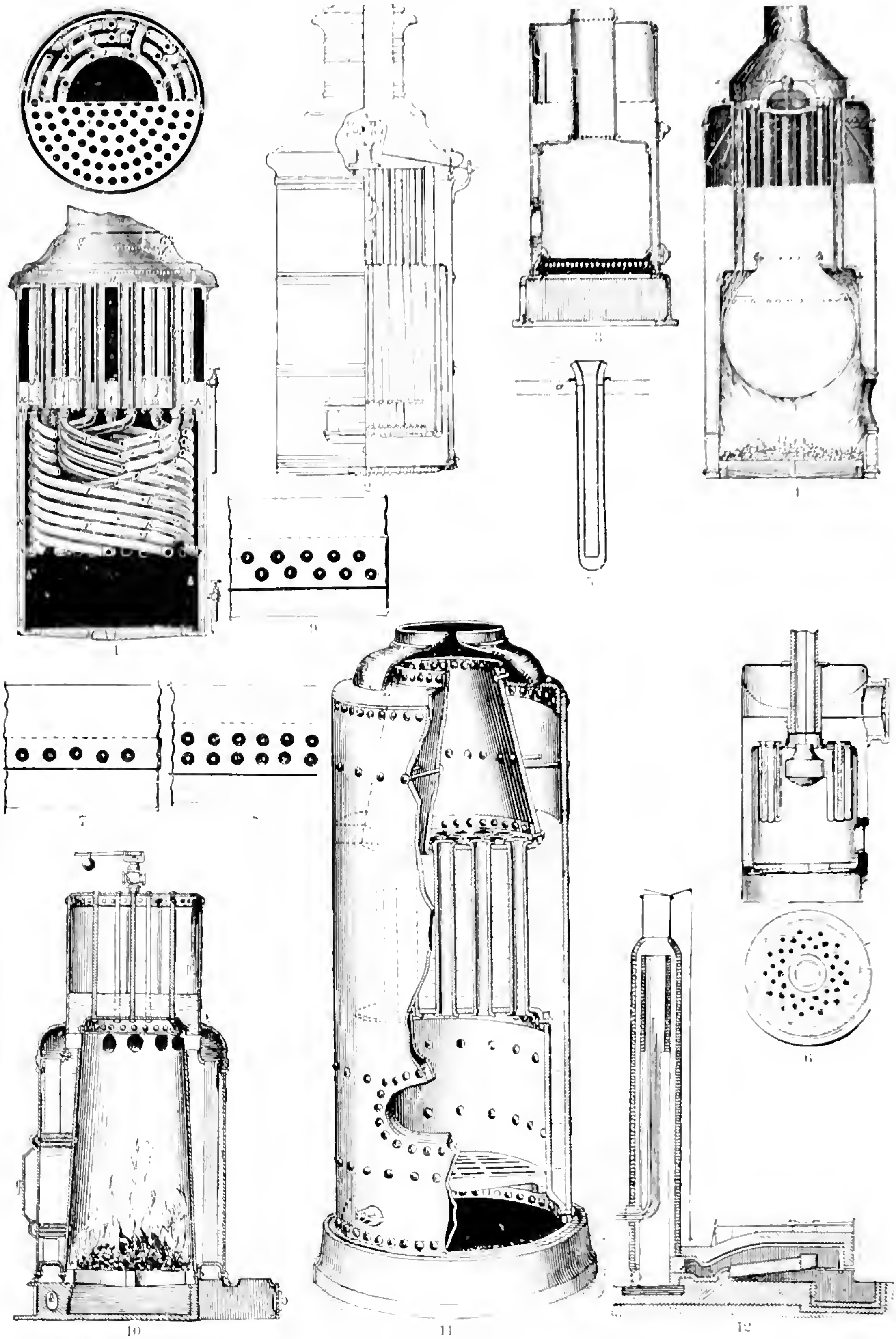
1. French or "elephant" boiler. 2. Compound tubular boiler. 3. Return-tube boiler. 4. "Cornish" boiler. 5. Round-end boiler with feed heater, low-water alarm, damper regulator, etc. 6. Lancashire boiler (cross-section). 7. Lancashire boiler (cross-section). 8. Lancashire boiler (longitudinal vertical section). 9. Lancashire boiler (longitudinal vertical section). 10. End perspective of a multitubular boiler. 11. Galloway boiler (cross-section). 12. Galloway boiler (longitudinal vertical section).



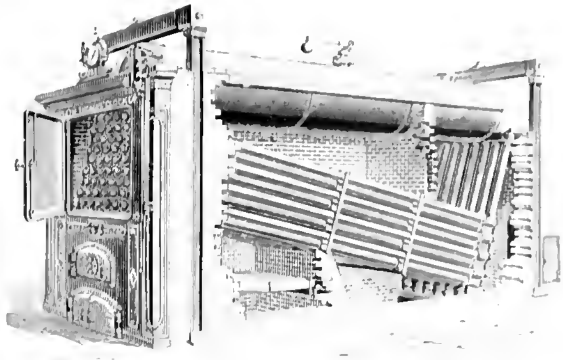
1. Vertical lengthwise section, 2. Cross-section, of Milholland's fire box for anthracite (1860, R[illegible] L[illegible] Works, Newark, N. J.). 3. Section, 4. Plan, of a finger grate. 5. Vertical lengthwise section of an ordinary [illegible] boiler. 6. Vertical lengthwise section, 7. Cross-section, of a "wagon top" boiler. 8. Cross-section, 9. Vertical lengthwise section, of a Wootten locomotive boiler.

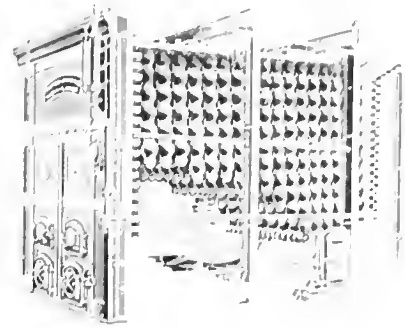


1. Lengthwise vertical section, 2. Cross-section, of the Buchanan fire-box (1871) of the [illegible] Valley R. R. 3. Lengthwise vertical section, 4. Cross-section, of the Belpaire fire-box (1874) of the Mata[illegible] R. R. [illegible] 5. Lengthwise vertical section, 6. Detail, of a brick arch (1865). 7. Cross-section, 8. Lengthwise vertical section, [illegible] (U. S. Revenue steamer "Lot M. Morrill"). 9. Cross-section, 10. Lengthwise vertical section, of a [illegible] (U. S. cruiser "Baltimore").



1. Plan and section of a sectional coil tube and flue, steam fire-engine boiler (Clapp & Jones Manufacturing Co., Hudson, N. Y.). 2. Submerged dome, flue, and drop-tube steam fire-engine boiler, part in section (Silsby Manufacturing Co., Seneca Falls, N. Y.). 3. Plain vertical boiler. 4. Thomson's vertical tubular boiler (vertical section). 5. Field's tube (enlarged). 6. Plan and section of Field's vertical tubular boiler. 7. Single, 8. Chain, 9. Zigzag, riveting. 10. Shapley vertical boiler (Shapley & Wells, Binghamton, N. Y.). 11. Vertical tubular boiler (Niles Tool Works, Hamilton, O.). 12. Vertical cylinder boiler attached to iron furnace.





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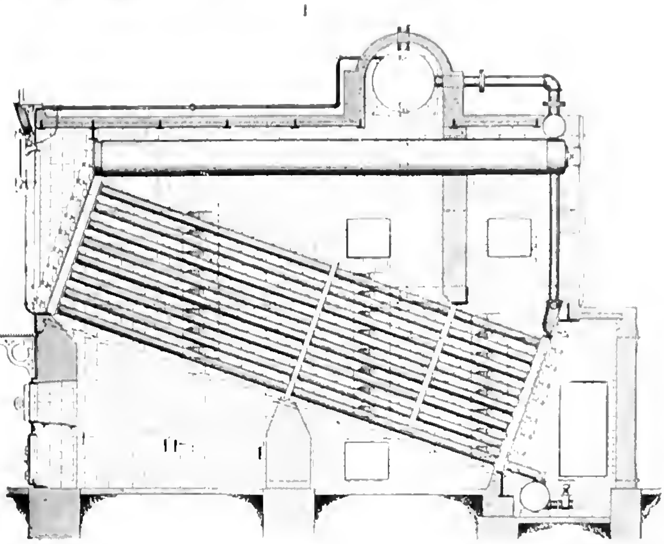

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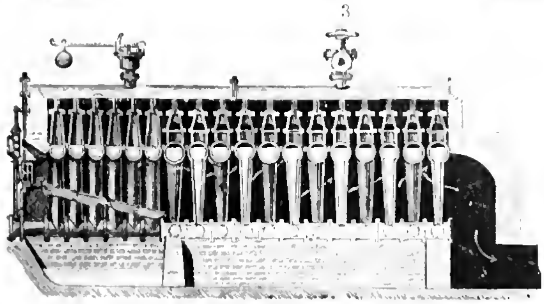

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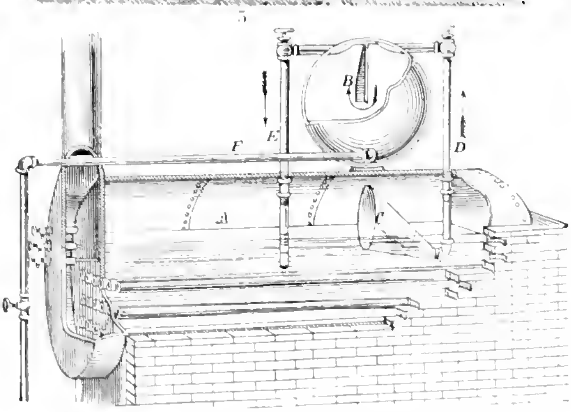

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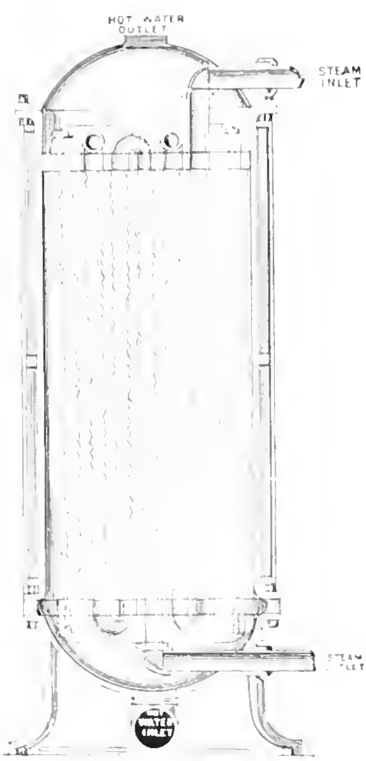

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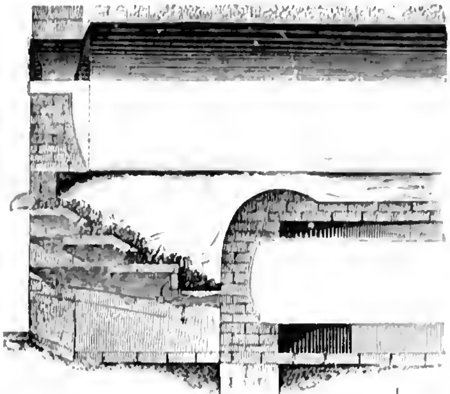
1. Water tube boiler (Babcock & Wilcox Co., New York). 2. Harrison cast [illegible] sectional boiler (Harrison [illegible] Works, Philadelphia). 3. Root boiler, sectional view, 15 feet tubes (Abendroth & Root Ma[illegible], New York). 4. Vert[illegible] section of the Sterling boiler (International Boiler Co., New York). 5. M[illegible] 6. Hel[illegible] mechanical boiler cleaner for heavy impurities. 7. Wainwright's corrugate[illegible] water heater.



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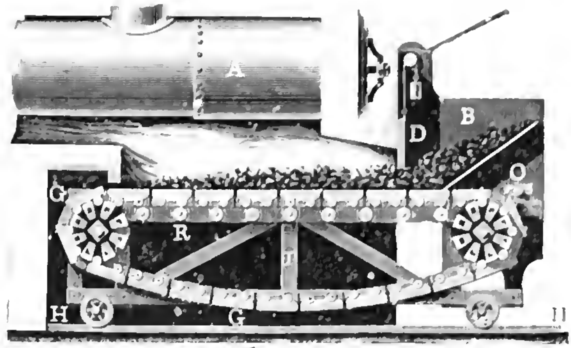

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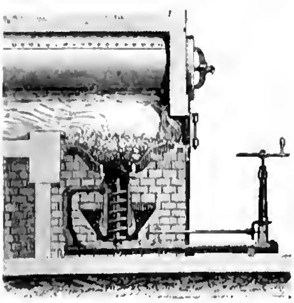

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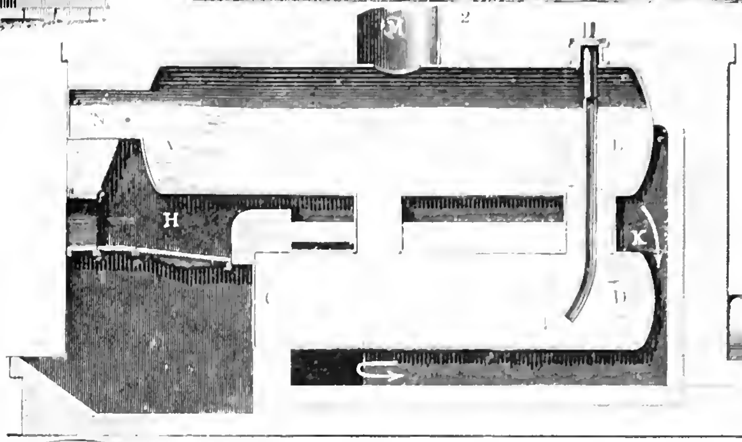

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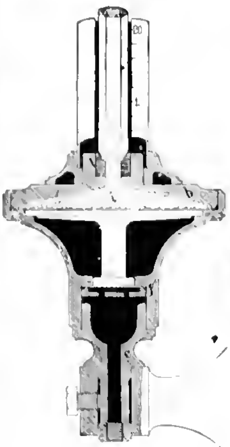

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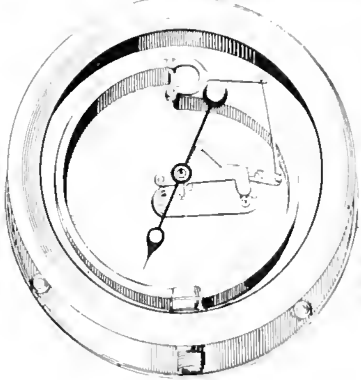

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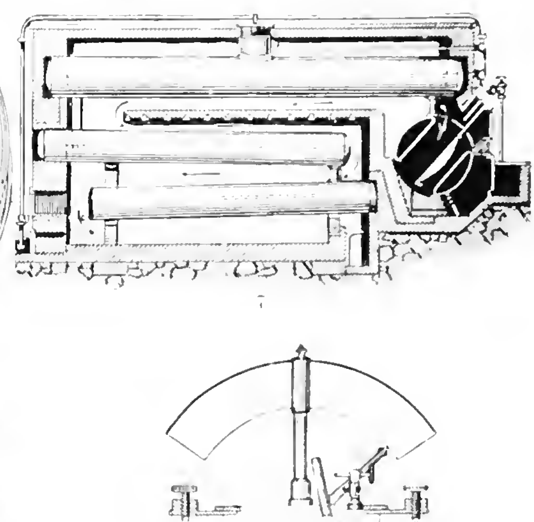

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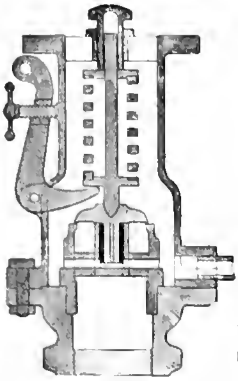

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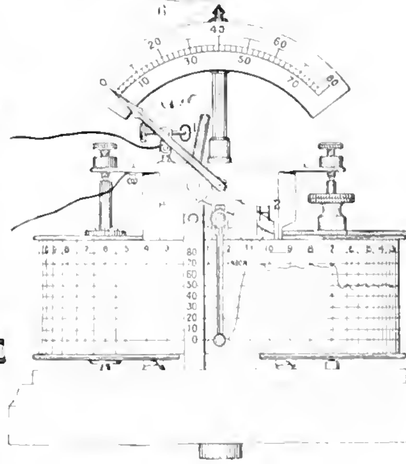

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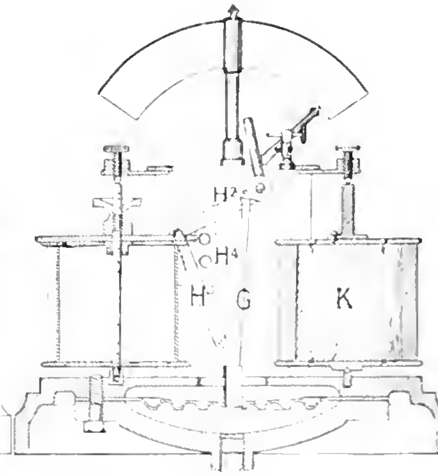
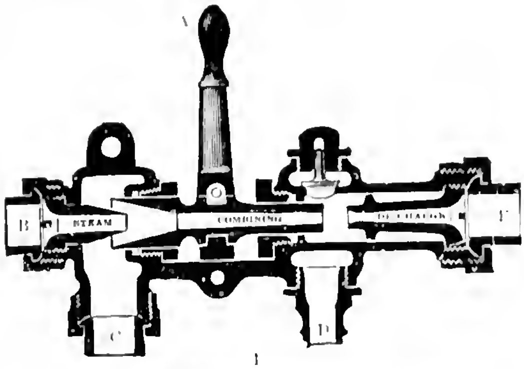


10

BOILER ACCESSORIES: 1. Langen's stepped-grate or smoke-consuming apparatus. 2. Juke's chain-grate or smoke-consuming apparatus. 3. George's screw grate or smoke-consuming apparatus. 4. Horizontal [illegible] boiler with heater for feed water. 5. Central vertical section of Shaw's differential mercury gauge (Thomas Shaw, [illegible]). 6. Crosby Bourdon steam dial pressure gauge (interior). 7. Ten Brink boiler setting. 8. "Pop" safety valve. 9. Elevation, 10. Vertical central section, of Edson's recording and alarm gauge.



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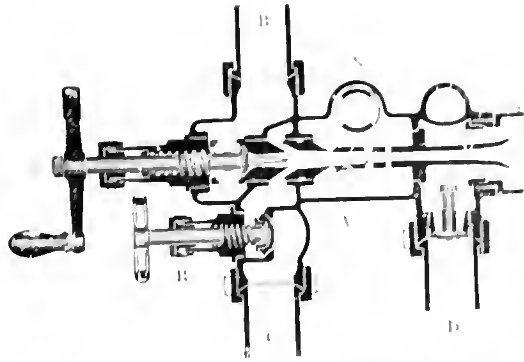

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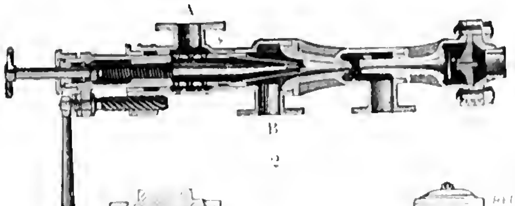

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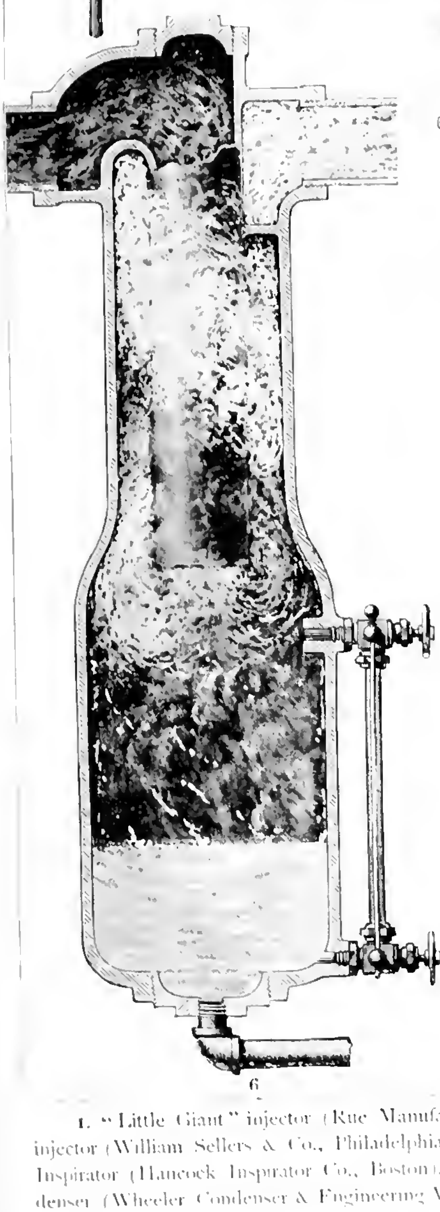

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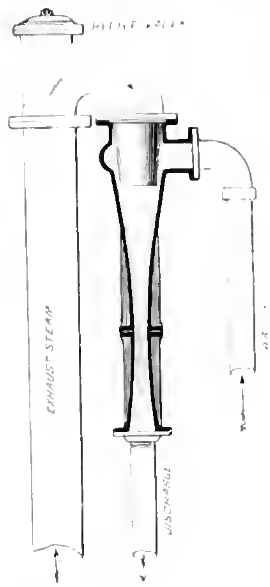

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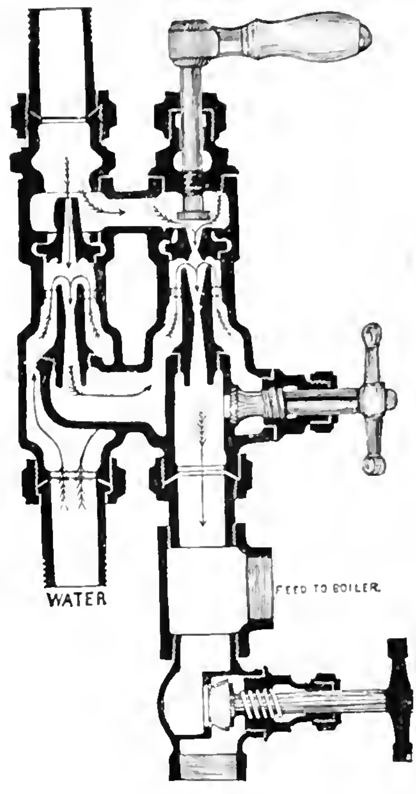

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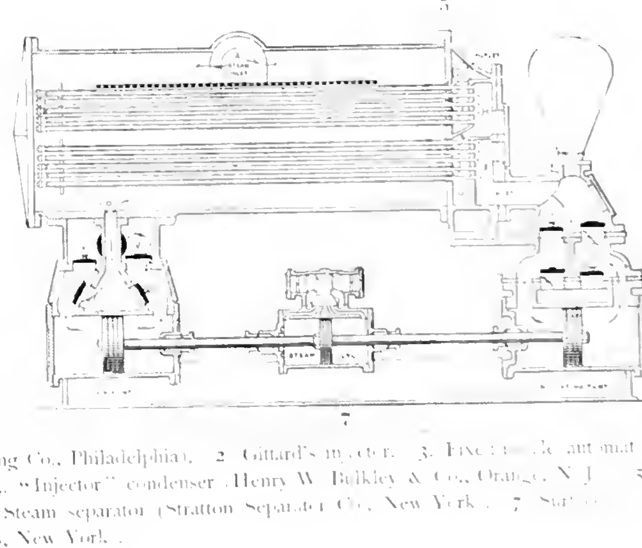

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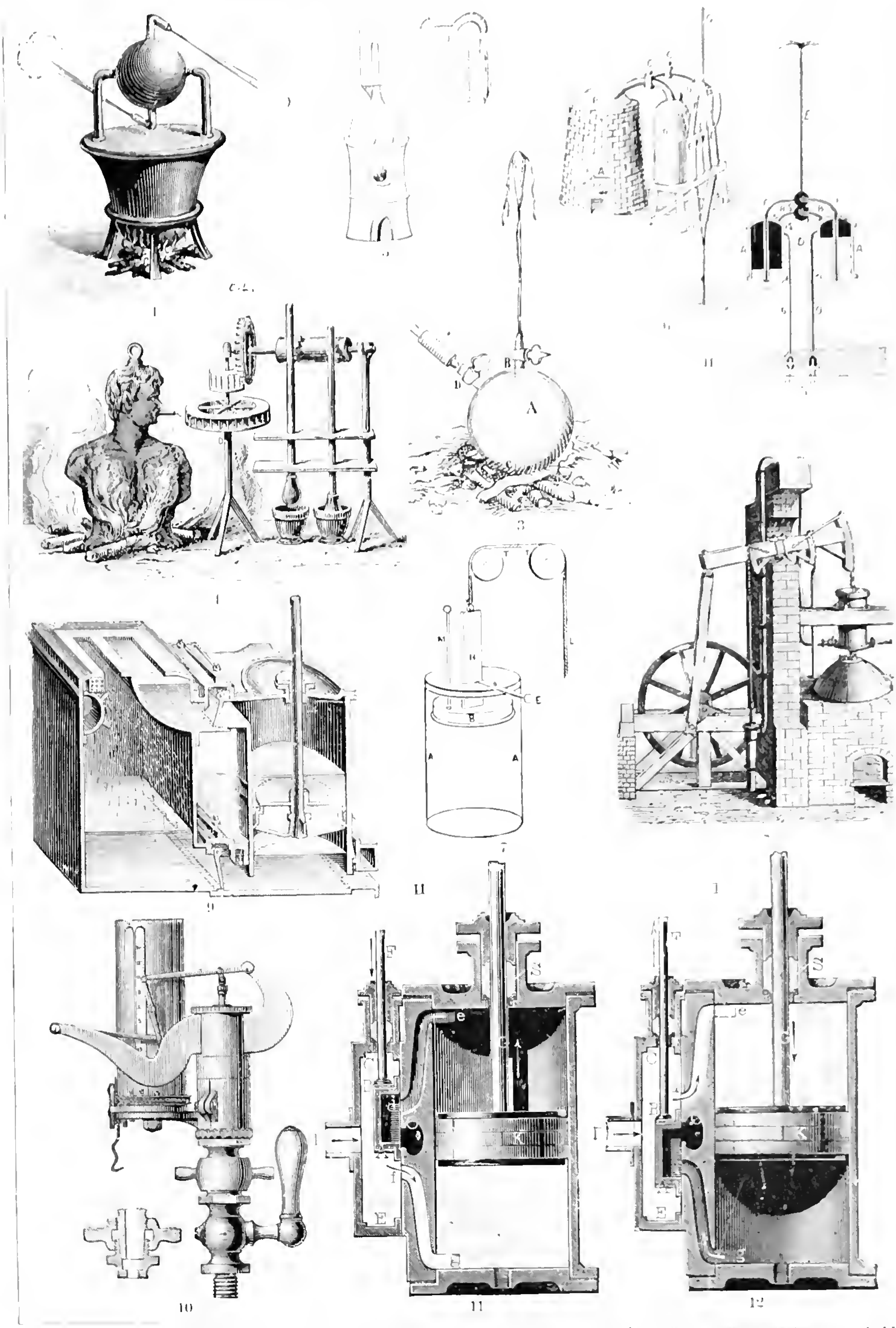
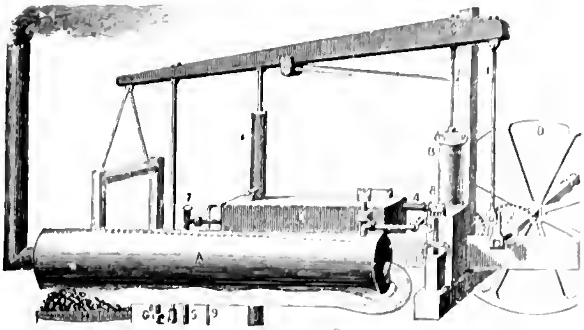
1. "Little Giant" injector (Rue Manufacturing Co., Philadelphia). 2. Gittard's injector. 3. Fixed nozzle automatic injector (William Sellers & Co., Philadelphia). 4. "Injector" condenser (Henry W. Bulkley & Co., Orange, N. J.). 5. Inspirator (Hancock Inspirator Co., Boston). 6. Steam separator (Stratton Separator Co., New York). 7. Surface condenser (Wheeler Condenser & Engineering Works, New York).



1. Hero's æolipile (120 B.C.). 2. Porta's steam apparatus (A.D. 1601). 3. De Caus's steam [illegible] (A.D. 1615). 4. Branca's steam apparatus (A.D. 1629). 5. Worcester's steam-engine (A.D. 1663). 6. Savery's steam [illegible] (A.D. 1698). 7. Papin's first steam-engine. 8. Newcomen's steam-engine. 9. Watt's steam condenser, lengthwise section. 10. Watt's steam indicator as improved by Richard. 11, 12. Lengthwise section of cylinder and steam chest showing [illegible] D-slide valve distribution.



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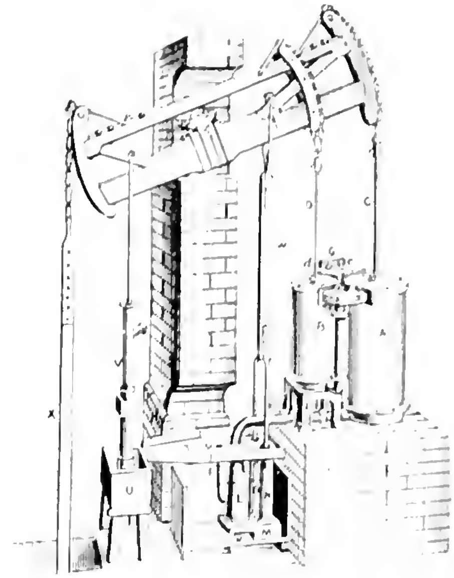

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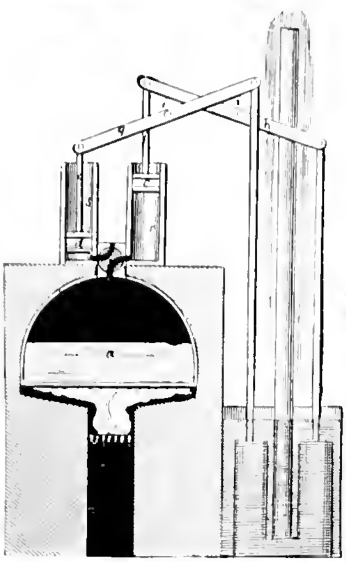

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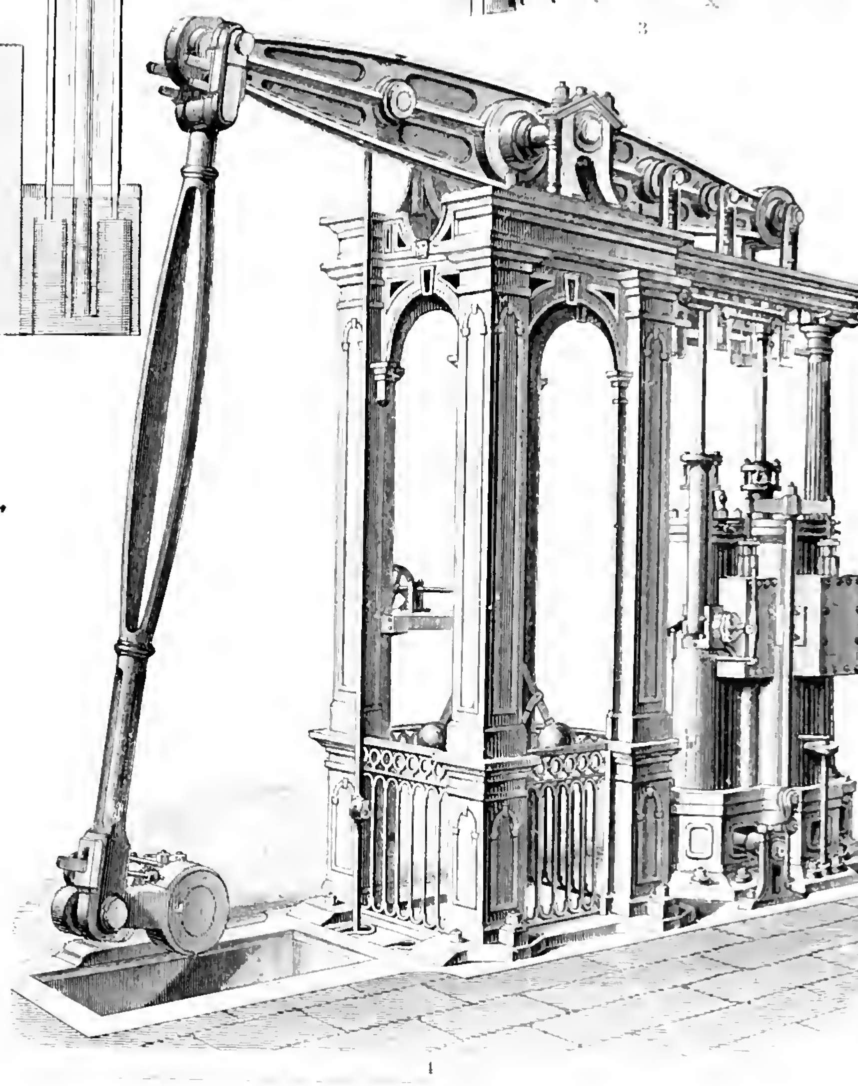

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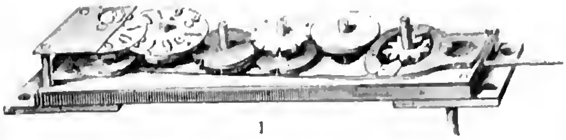
1. Leupold's steam-engine (A.D. 1720). 2. Oliver Evans's "Columbian" non-condensing steam-engine (A.D. 1800).
3. Hornblower's compound non-condensing engine (A.D. 1781). 4. Woolf's double-cylinder beam-engine.



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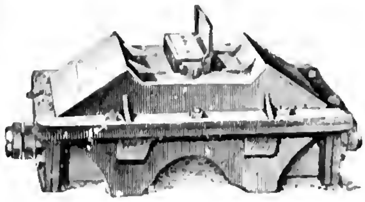

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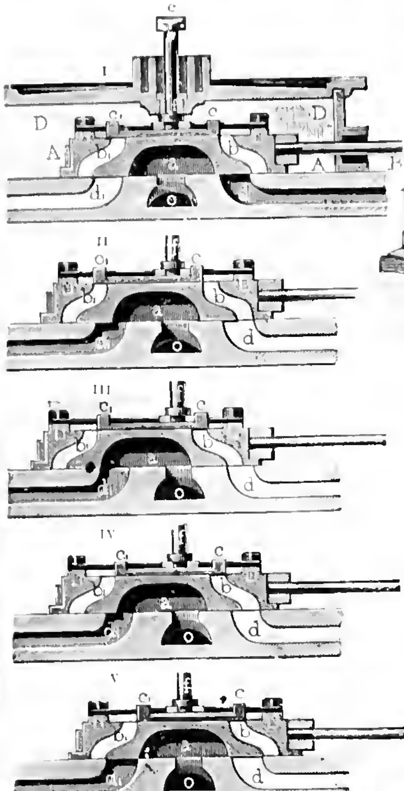

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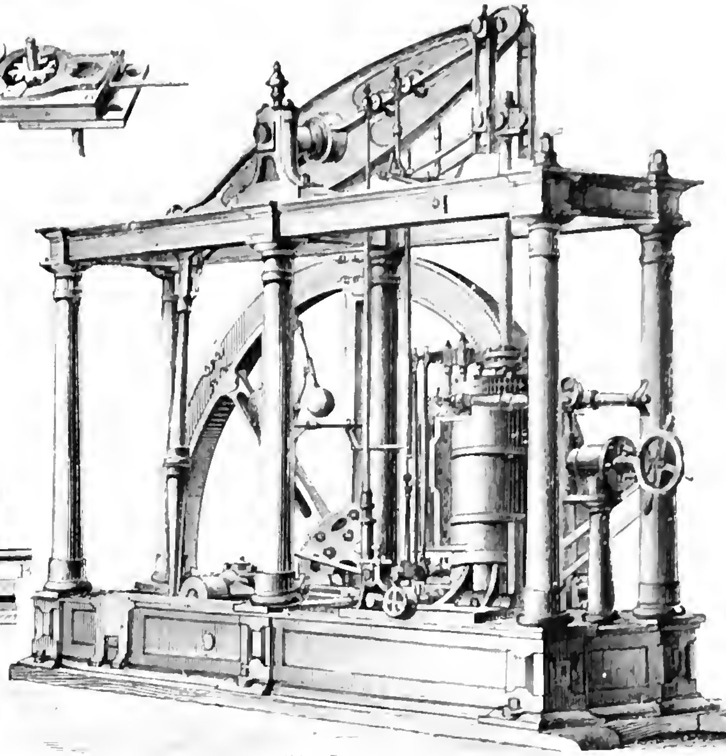

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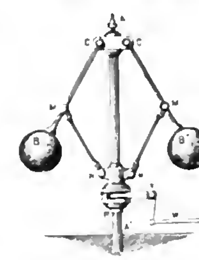

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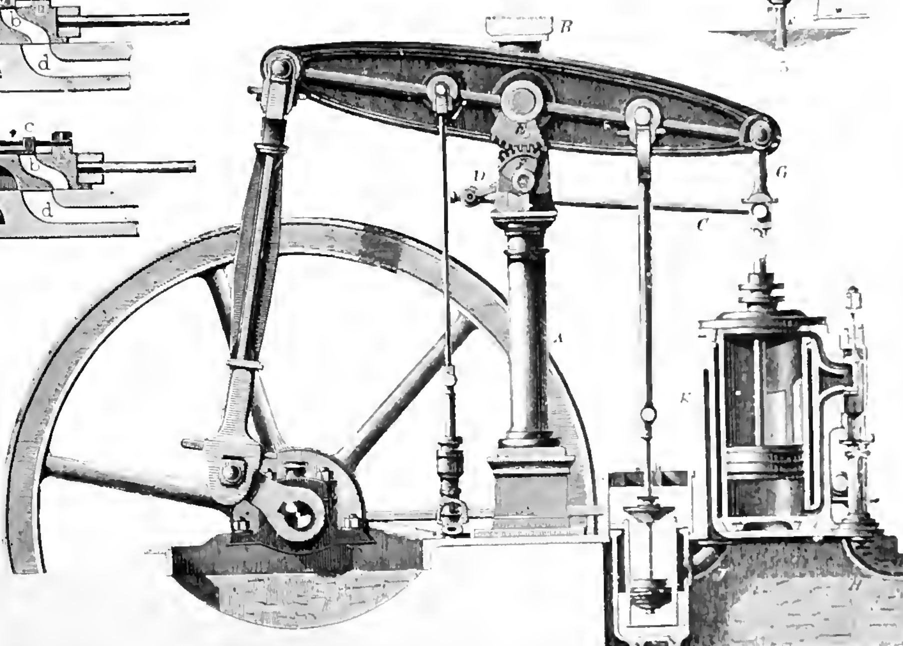

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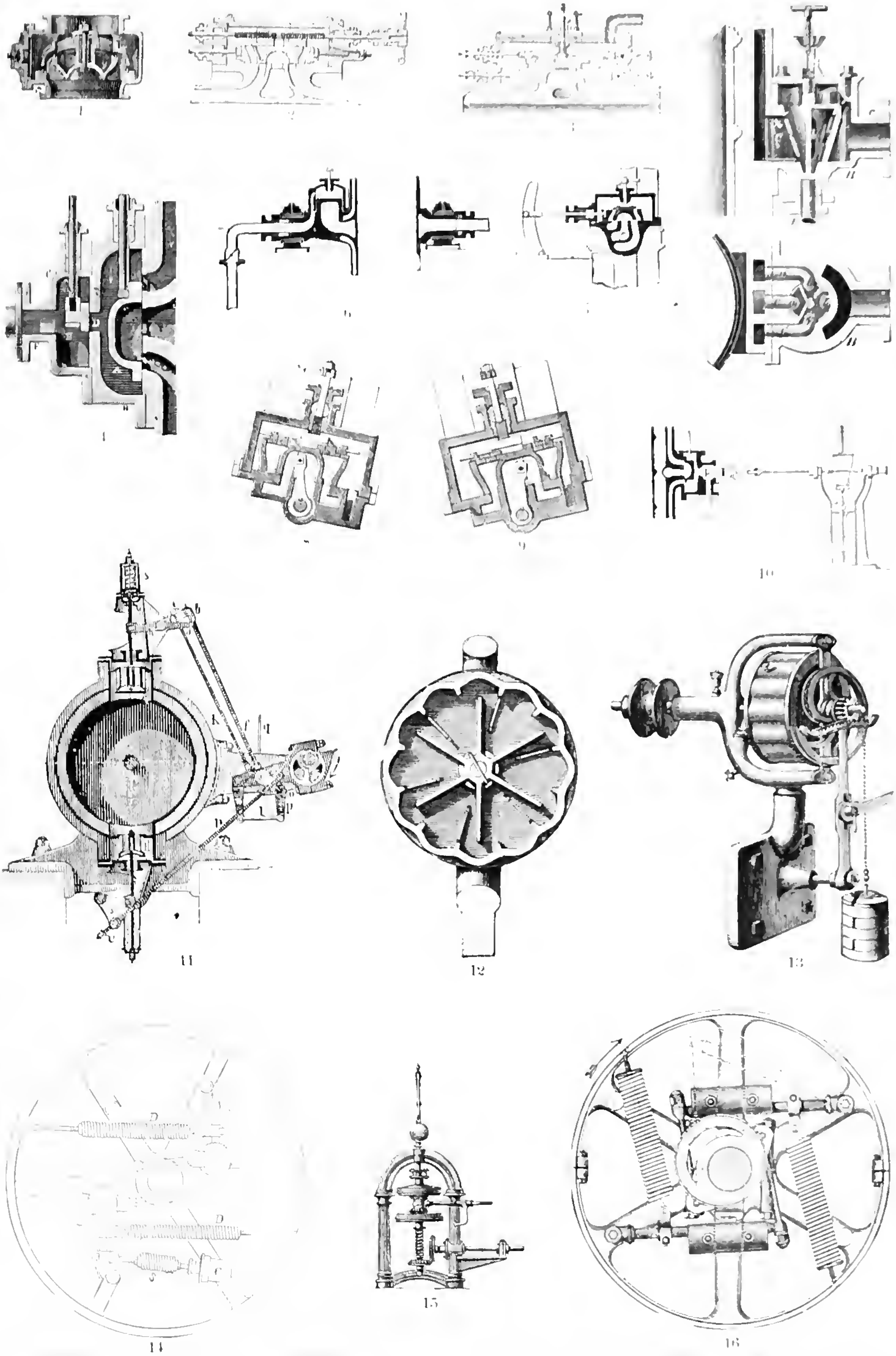
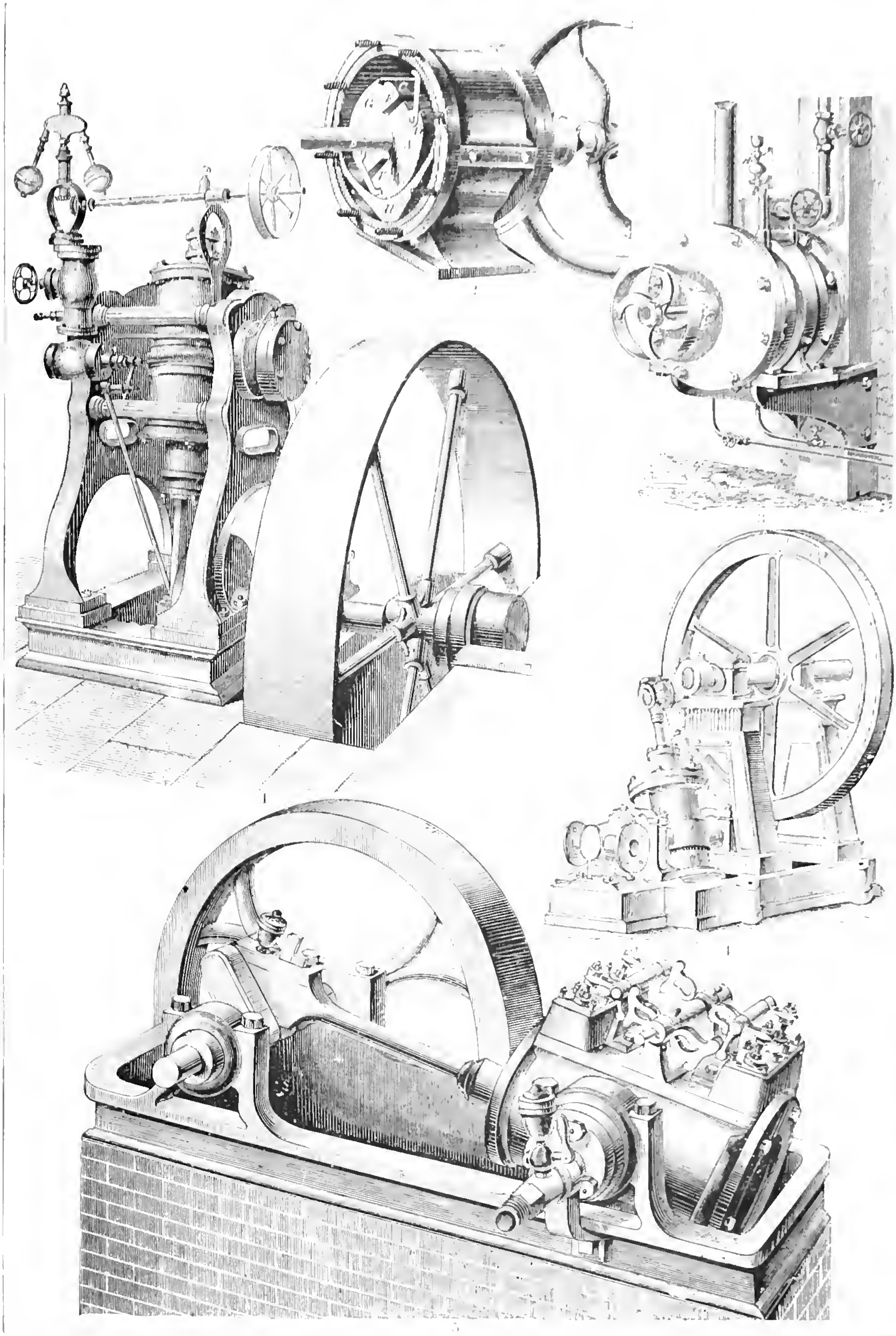
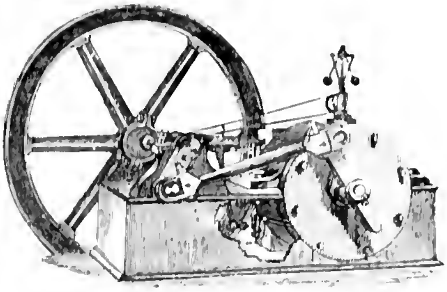
1 Recorder. 2 Water meter. 3 Valve motion, Farcot's slide valve. 4 Watt type of beam engine (perspective). 5 Watt fly-ball governor. 6. Watt type of beam engine (vertical section).



1–11. VALVES: 1. Double seat poppet valve, 2. Meyer's variable cut-off slide valve, 3. George distributing valve, 4. Gonzenbach valve, 5. 9. Oscillating engine valves, 10. Meyer throttling-valve with governor, 11. Sulzer poppet-valve gear. 12–16. GOVERNORS: 12. Cross-section, 13. Perspective, of the Allen governor, 14. Ball's regulator governor, 15. Farcot's centrifugal governor, 16. Hartnett "Buckeye" governor.



1. Mackintosh's oscillating-engine. 2. Furner's rotary-engine. 3. Cox's rotary-engine. 4. Hick's oscillating-engine. 5. Westland's oscillating-engine.



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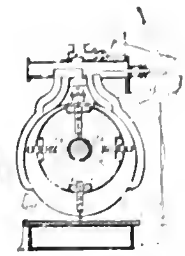

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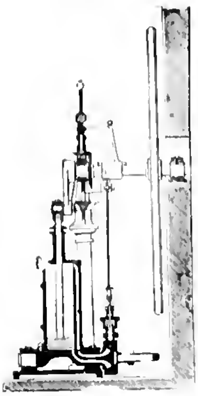

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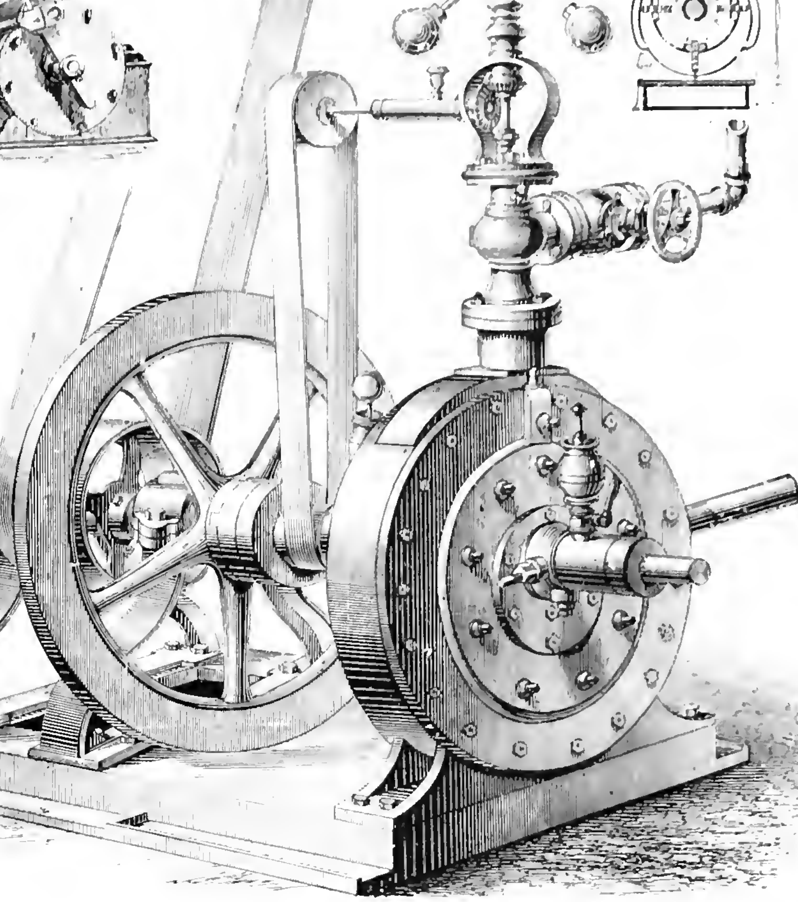

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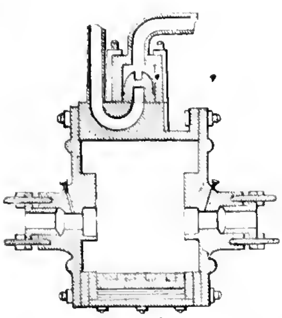

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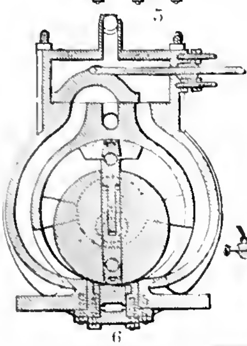

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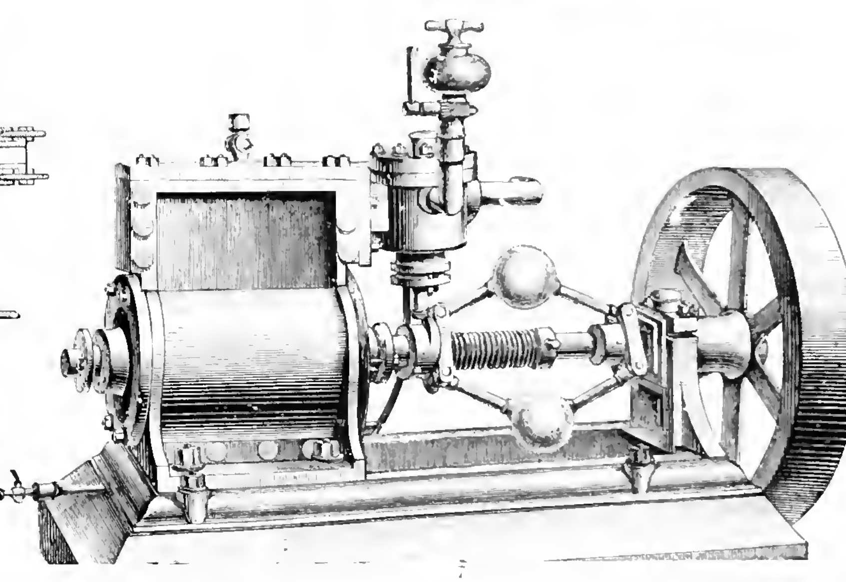
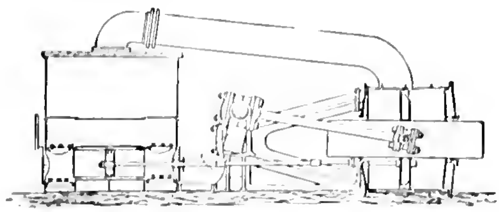


7

1. Runkel's rotary-engine. 2. Borne's rotary engine (cross section). 3. Fevre's oscillating engine (lengthwise and cross section). 4. Root's rotary engine. 5, 6. Kenyon's rotary engine (lengthwise and cross sections). 7. Hall's rotary-engine.



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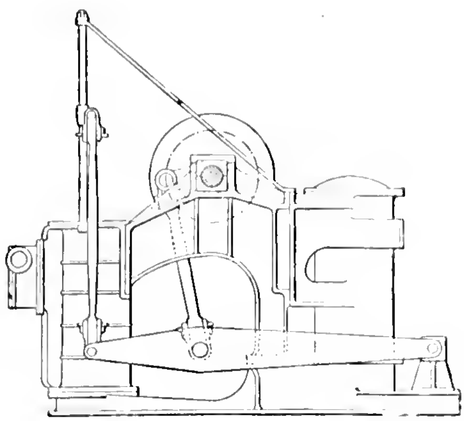

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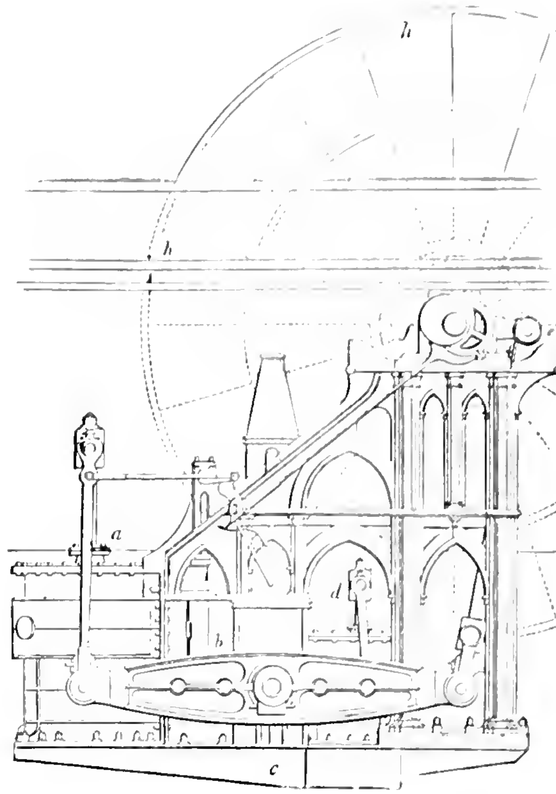

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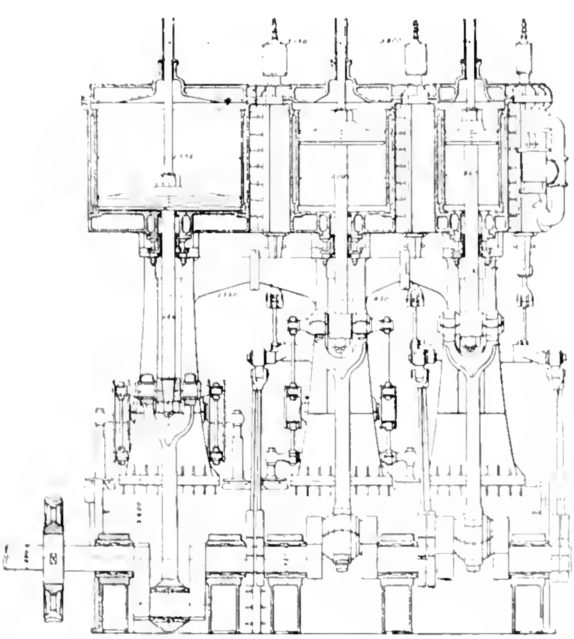

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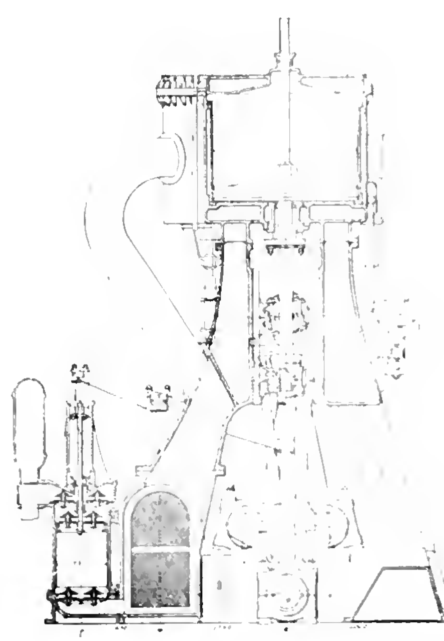
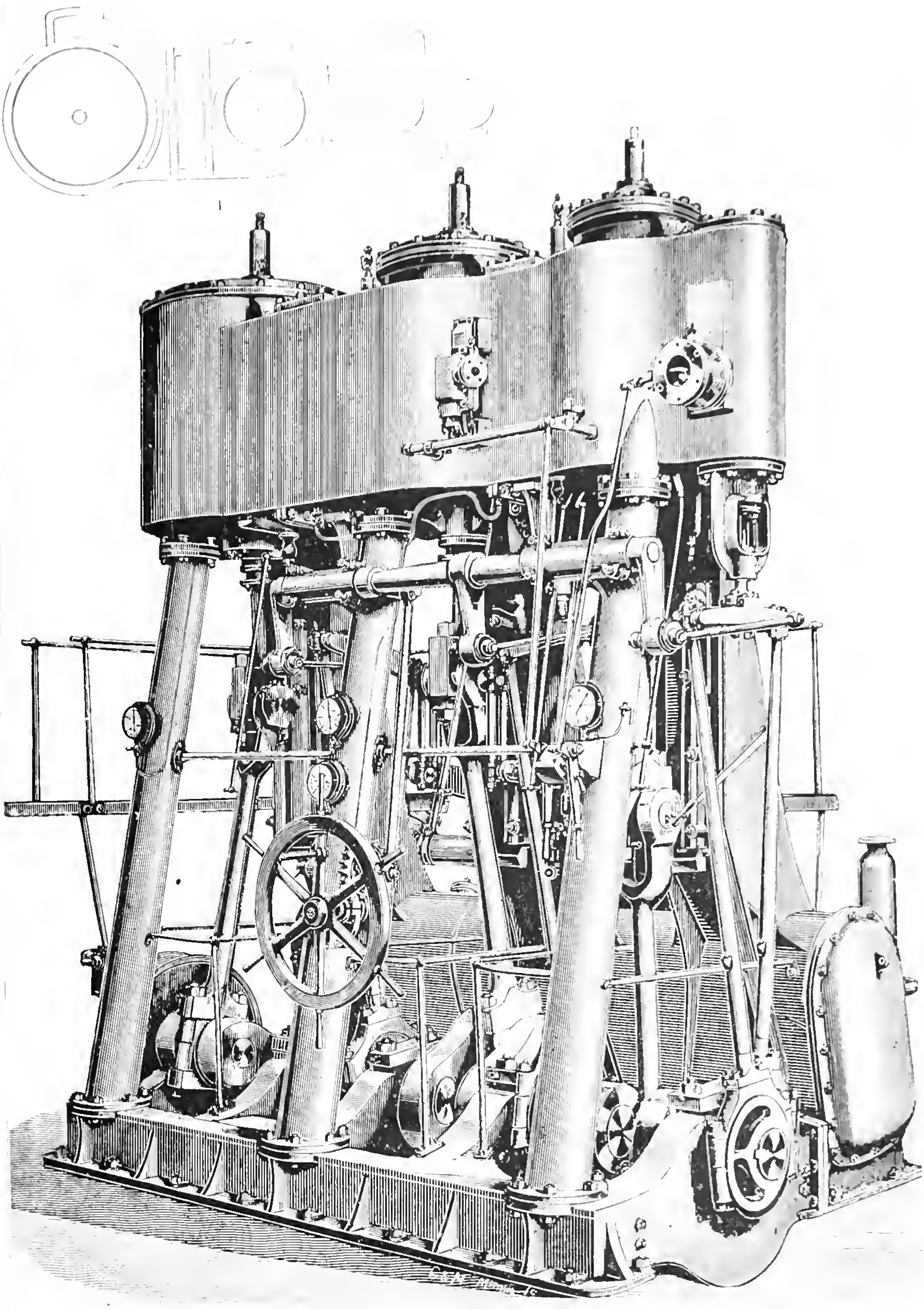
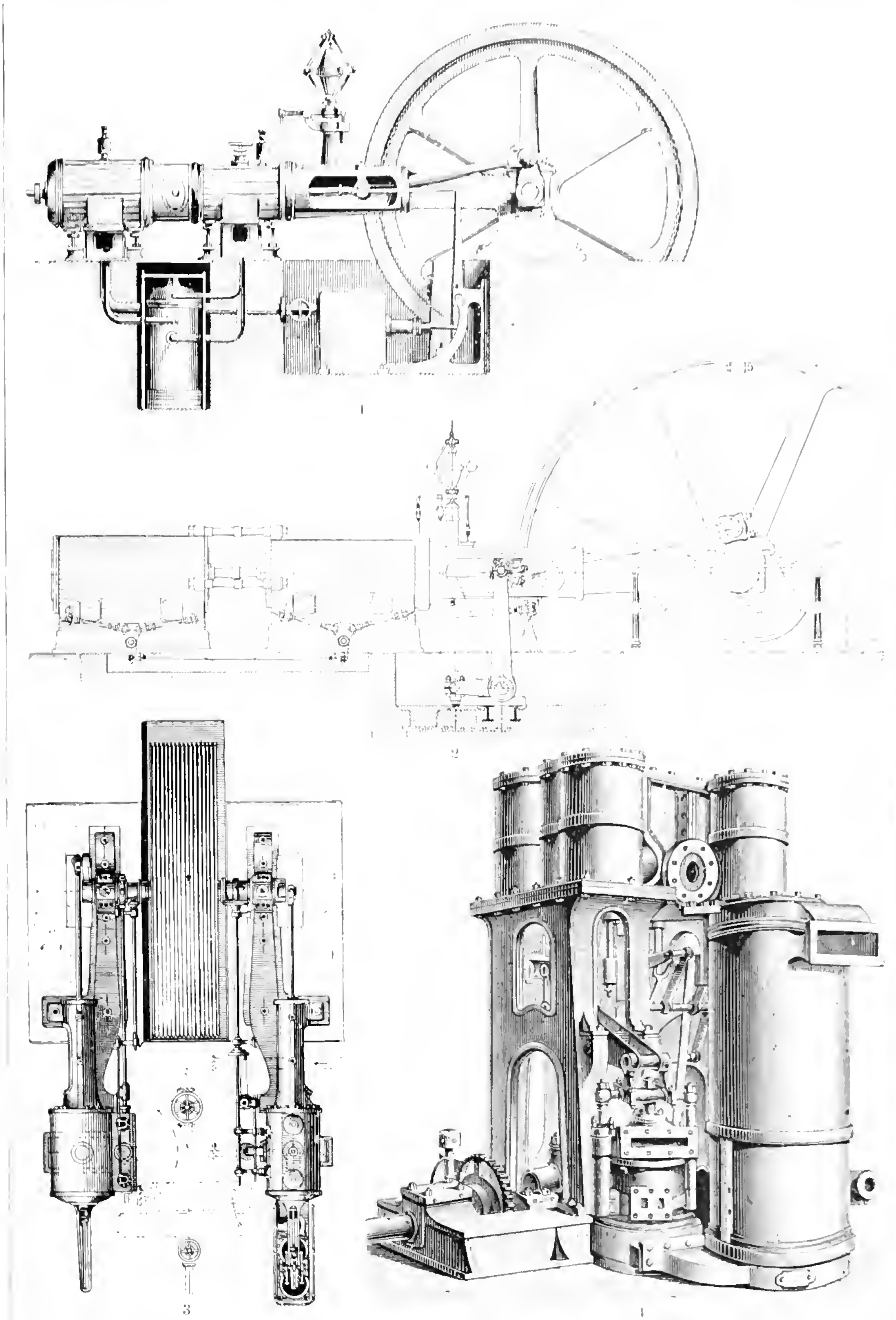


5

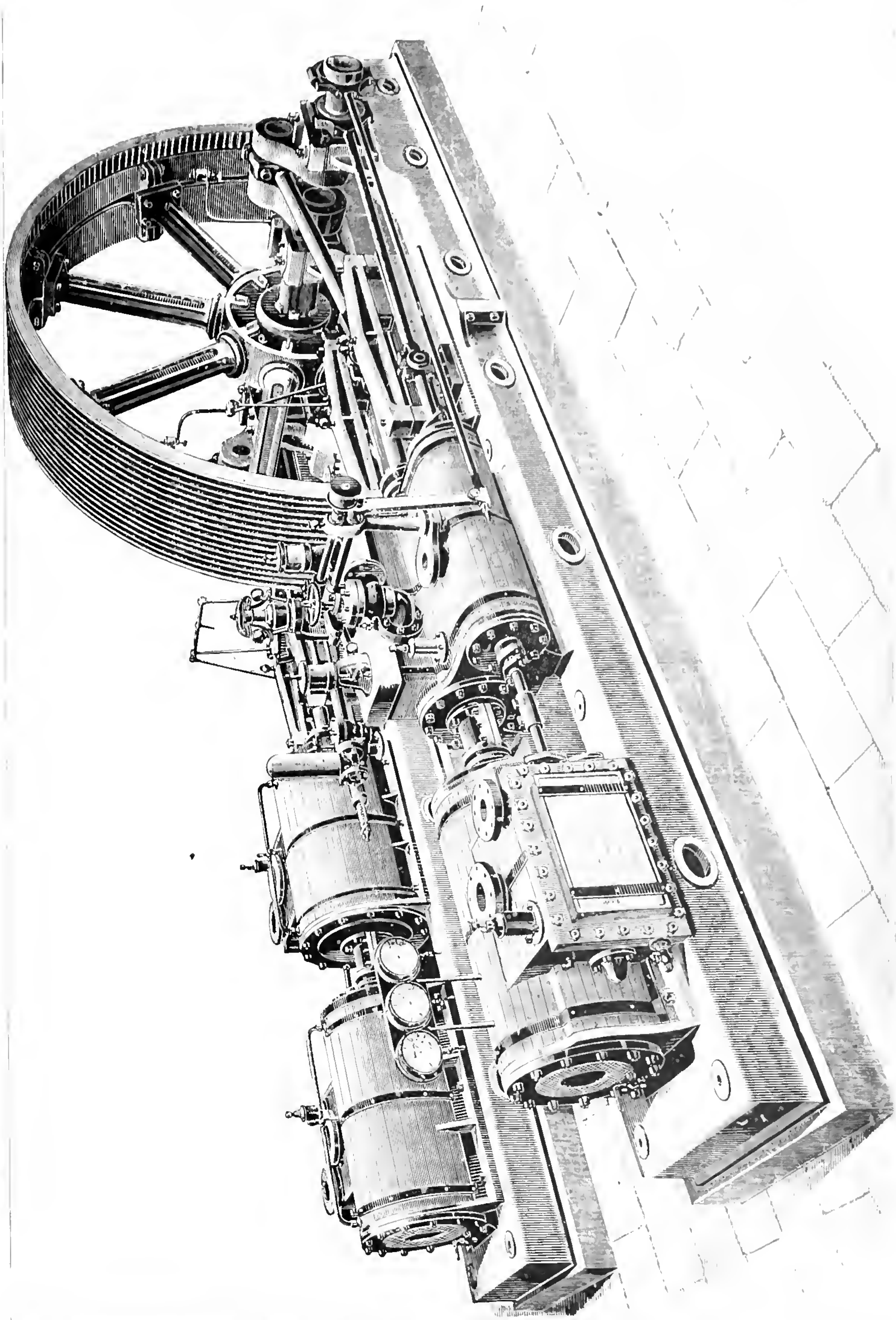
1. Penn's marine trunk-engine. 2. "Grasshopper" side-lever paddle engine. 3. S[illegible] on the Cunard Line of Atlantic side-wheel steamers. 4. Vertical lengthwise section, 5. Vertical cross-section, [illegible] 1800-horse-power triple-expansion marine steam-engine (E. Cravero & Co., Genoa, Italy).

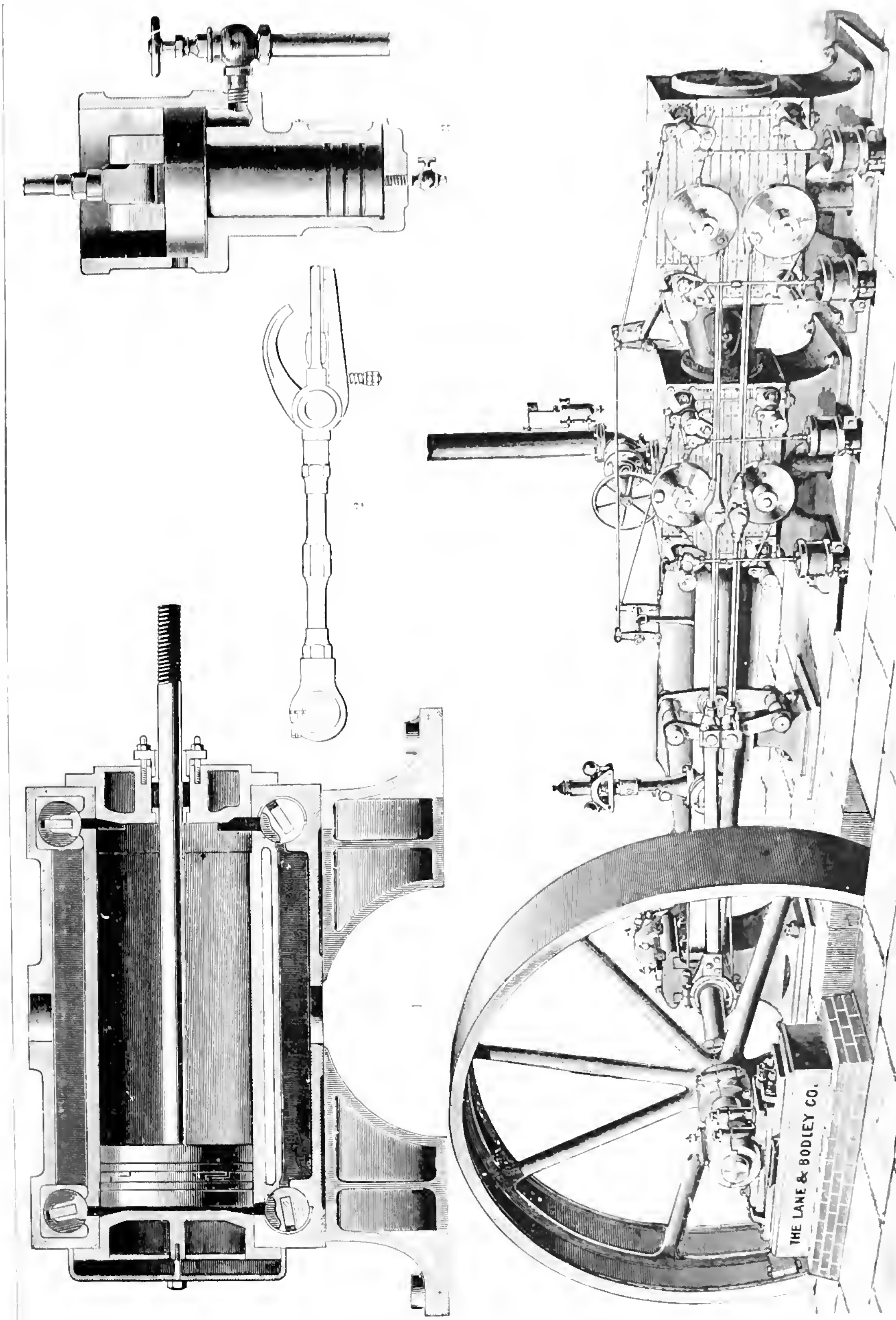


1. Plan of cylinders, 2. Perspective, of triple expansion marine engine of the Steam[illegible] W[illegible] Co., Middlesborough-on-Tees)

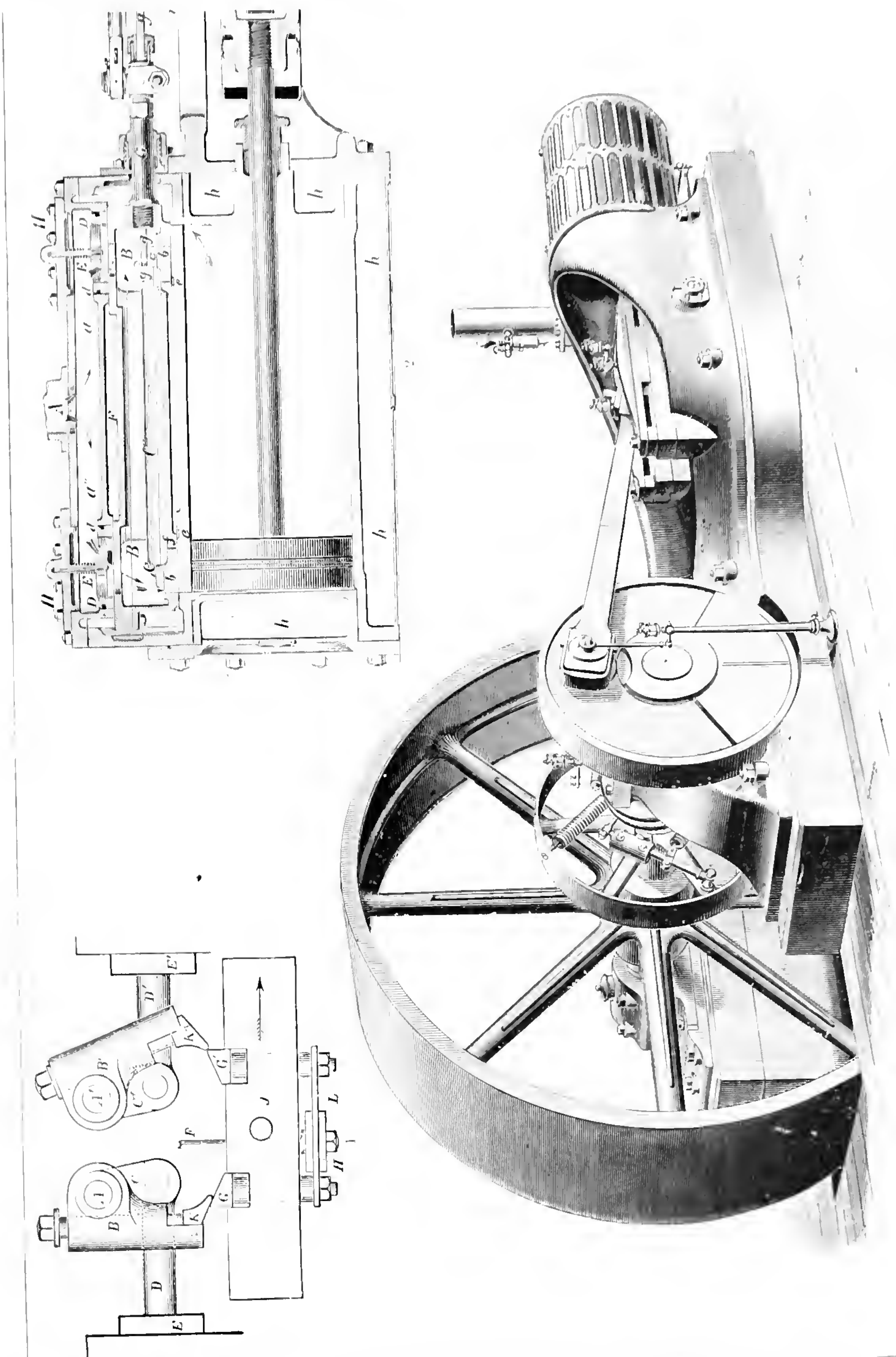


1. Tandem compound condensing steam-engine (Escher, Wyss & Co., Zurich). 2. Hori[illegible] expansion engine, Paris Exhibition, 1880 (Ateliers Powell, Rouen, France). 3. Collmann's [illegible] steam-engine. 4. Rowan's twin triple compound steam engine.

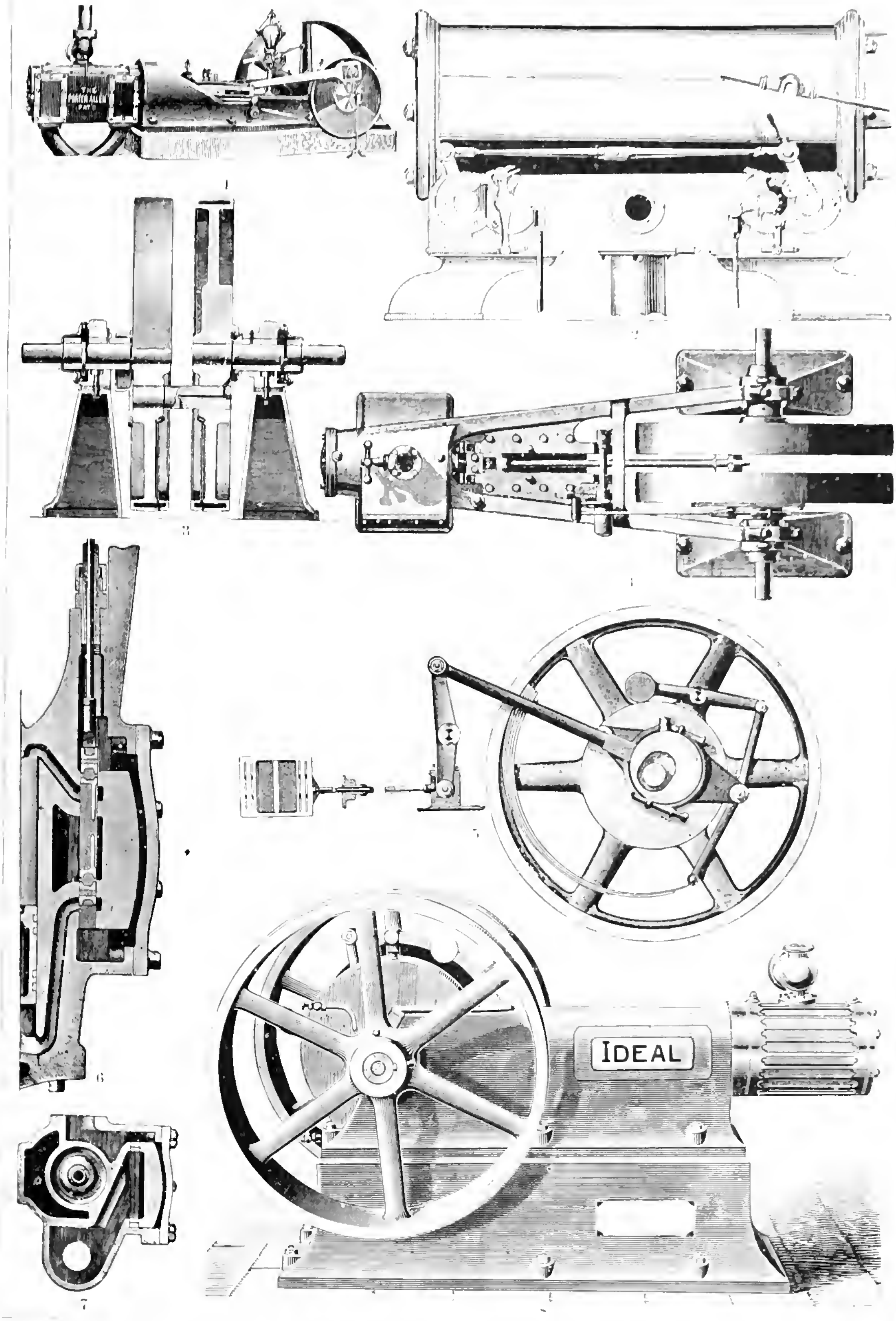




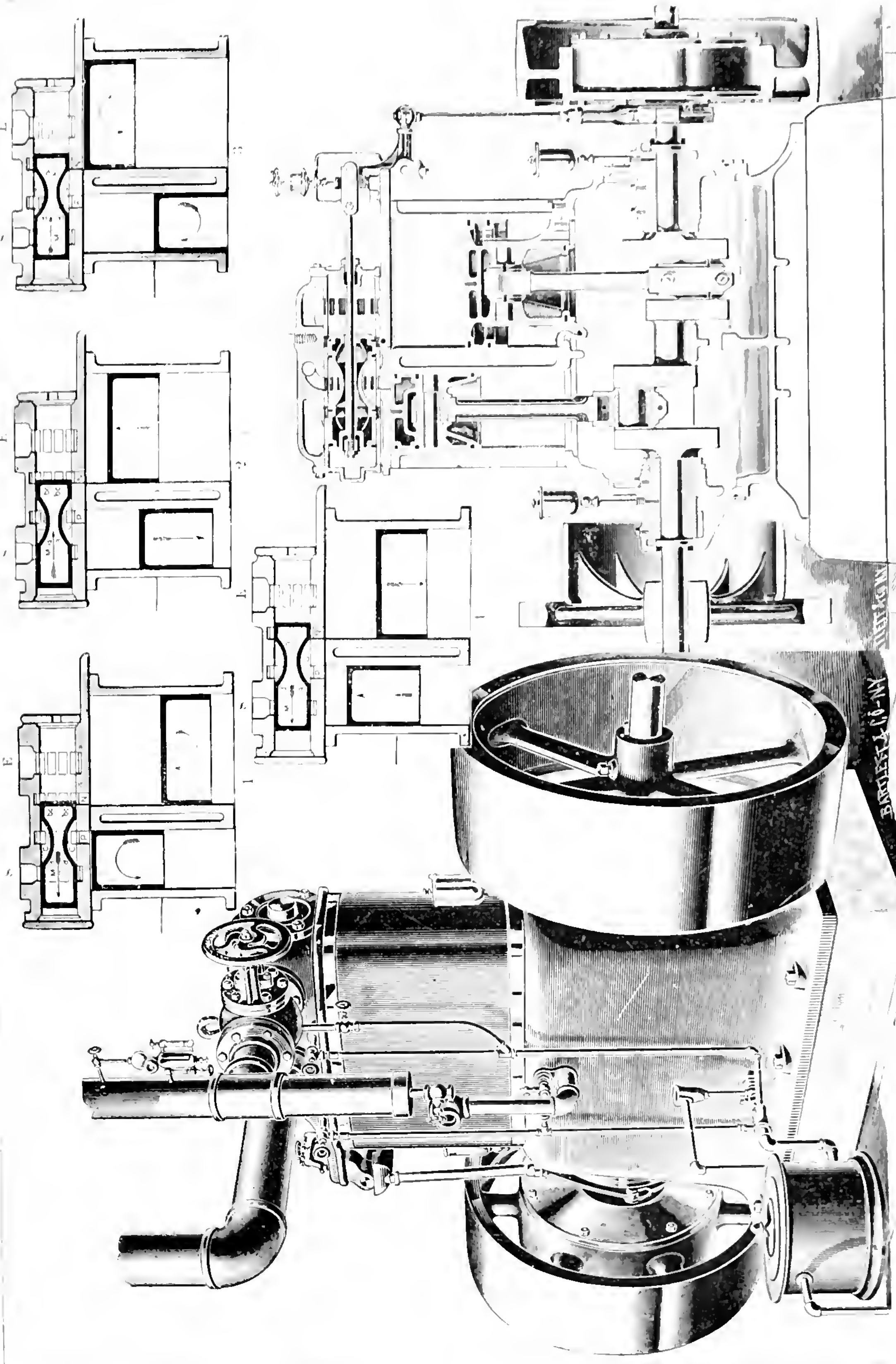
1. Cylinder (longitudinal vertical section), 2. Crab-claw, 3. Dash-pot (vertical section), of an improved Corliss engine. 4. [illegible] Co., Cincinnati.



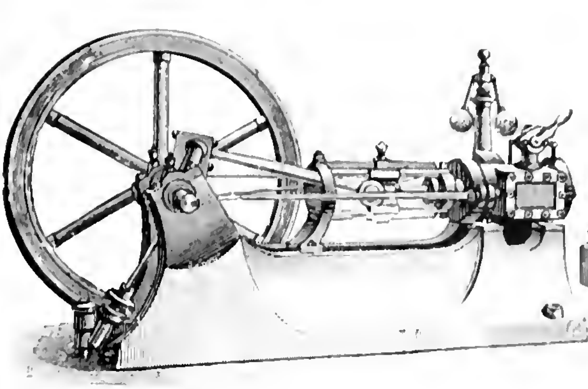
1. Valve-motion of the Greene engine. 2. Horizontal longitudinal section of cylinder and valves. 3. Perspective of the Larger



1. Porter-Allen high-speed engine (Southwark Machine Co., Philadelphia). 2. Wheelock engine (Wheelock Steam-engine Works, Worcester, Mass.). 3. Vertical section through wheels and shaft, 4. Plan, 5. [illegible] 6. Section of cylinder and valves, 7. Cross-section of cylinder, of the "Straight Line" engine (Straight Line Engine Co., Syracuse, N. Y.). 8. "Ideal" engine (A. L. Ide & Son, Springfield, Ill.).



1-4. Lengthwise vertical sections, showing valve motion; 5. Perspective, 6. Vertical section, of the Westinghouse high-speed compound ... W... engine ... Machine Co., Pittsburgh.



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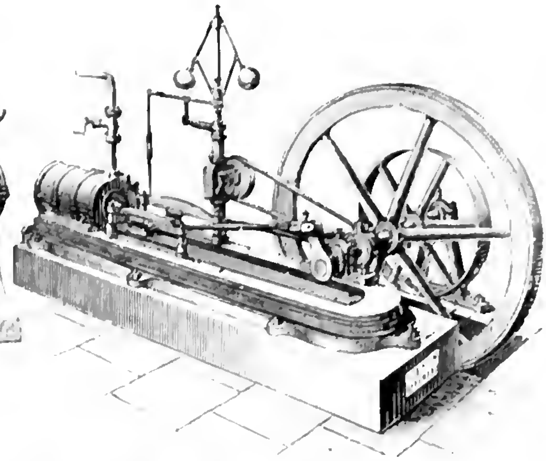

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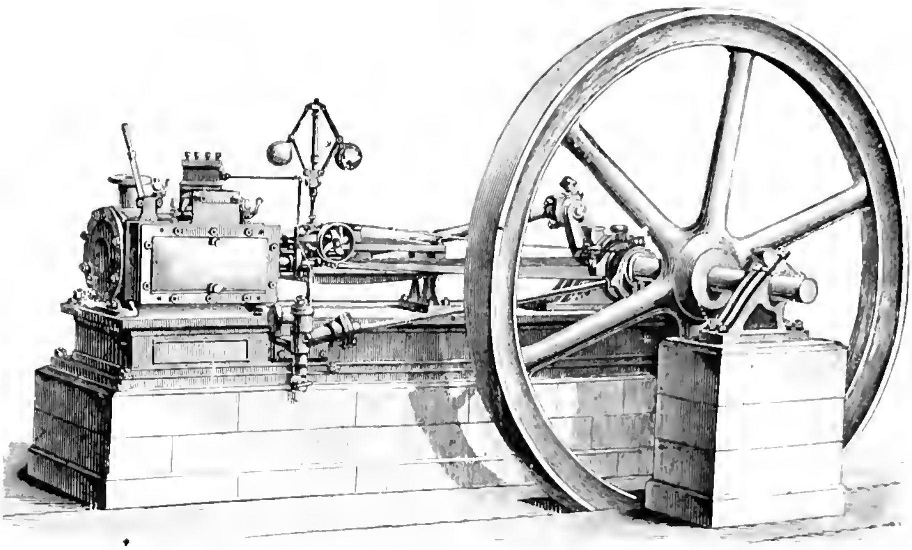

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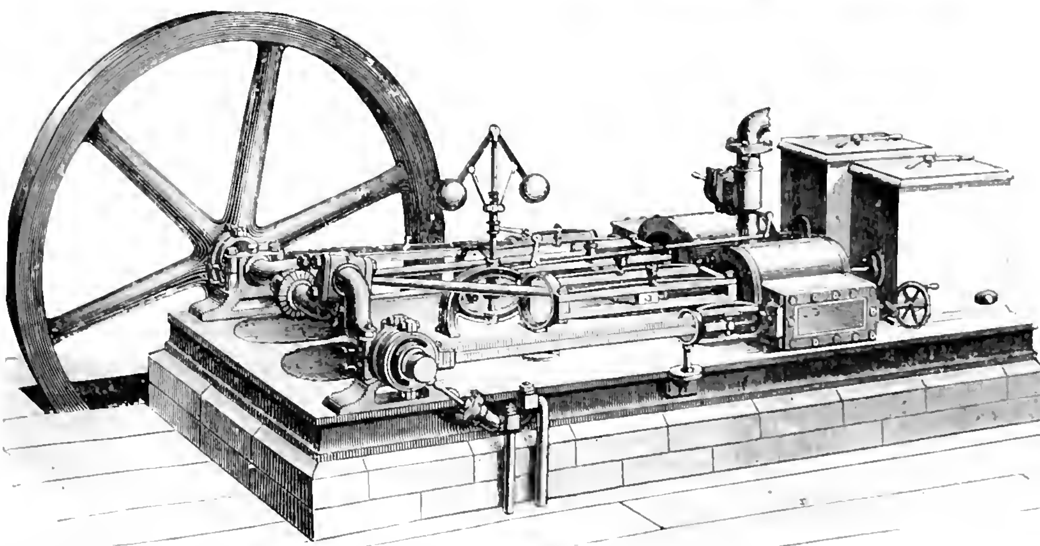
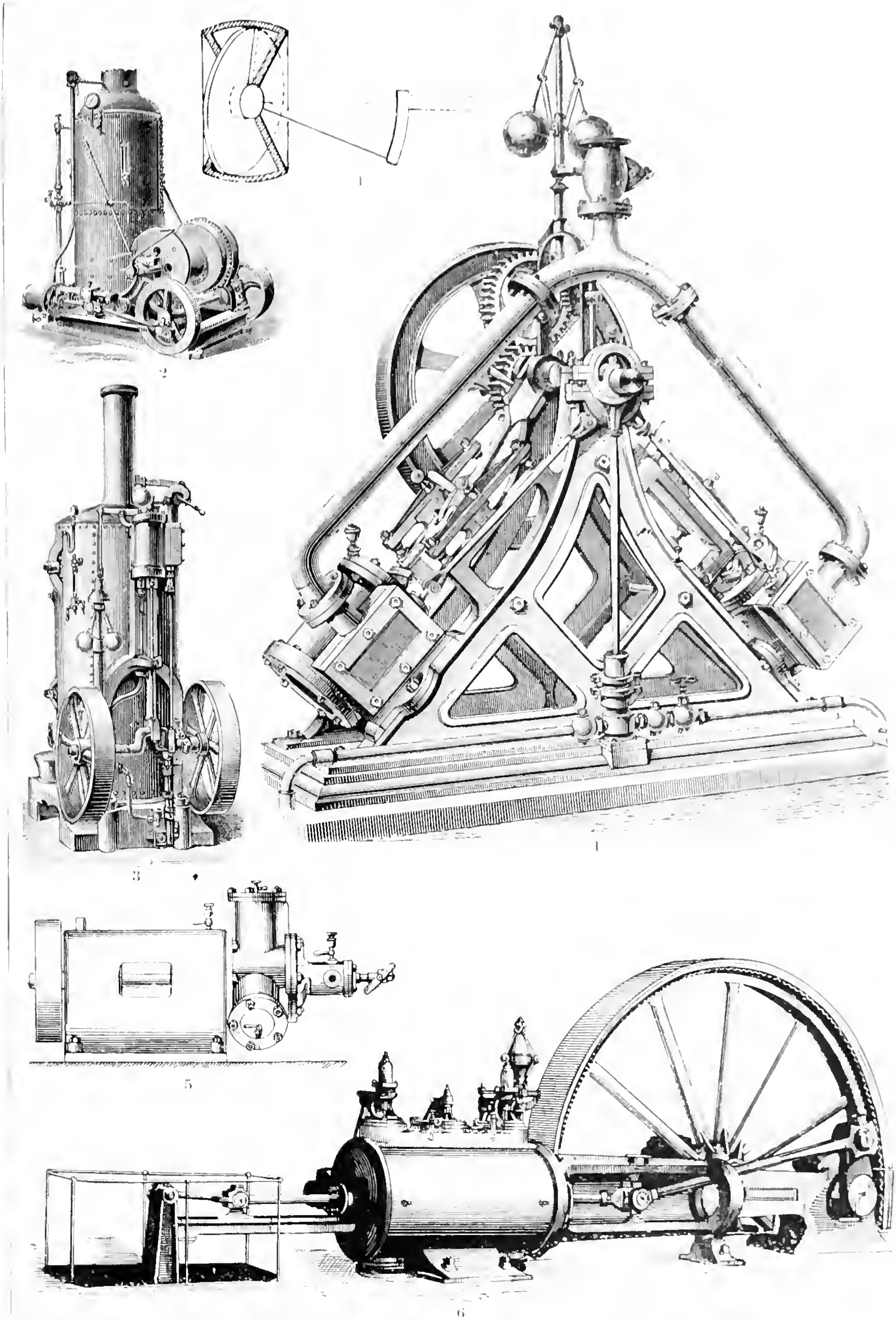
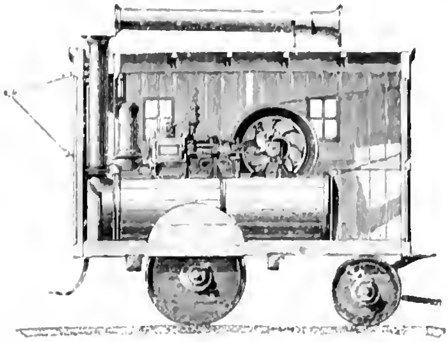


4

1. Small single cylinder, 2. Medium single cylinder, 3. Large single cylinder, 4. Double cylinder, [illegible]



1. Section of disc engine. 2. Hoisting engine with boiler attached (Edgerwood Manufacturing Co., New York). 3. Engine attached to boiler. 4 Inclined double-cylinder engine. 5 Side elevation of a three-cylinder engine. 6. Sulzer's condensing steam engine with back rod working an air pump.



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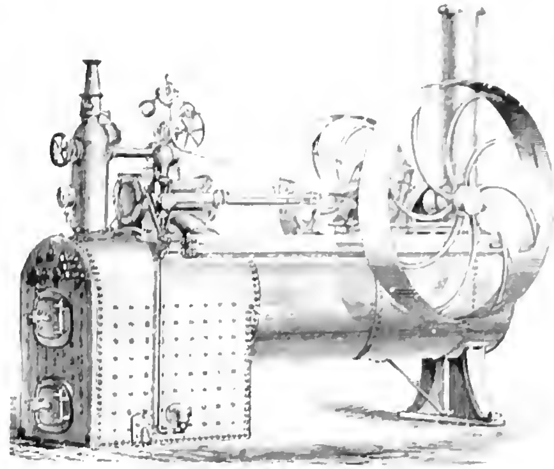

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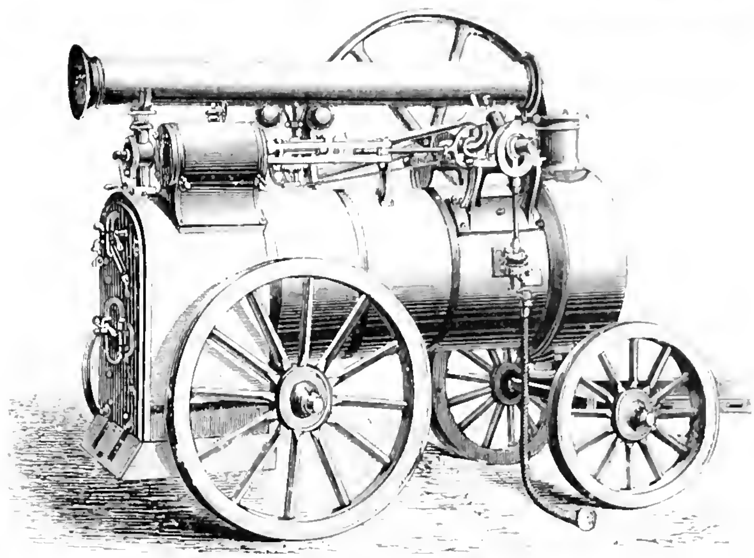

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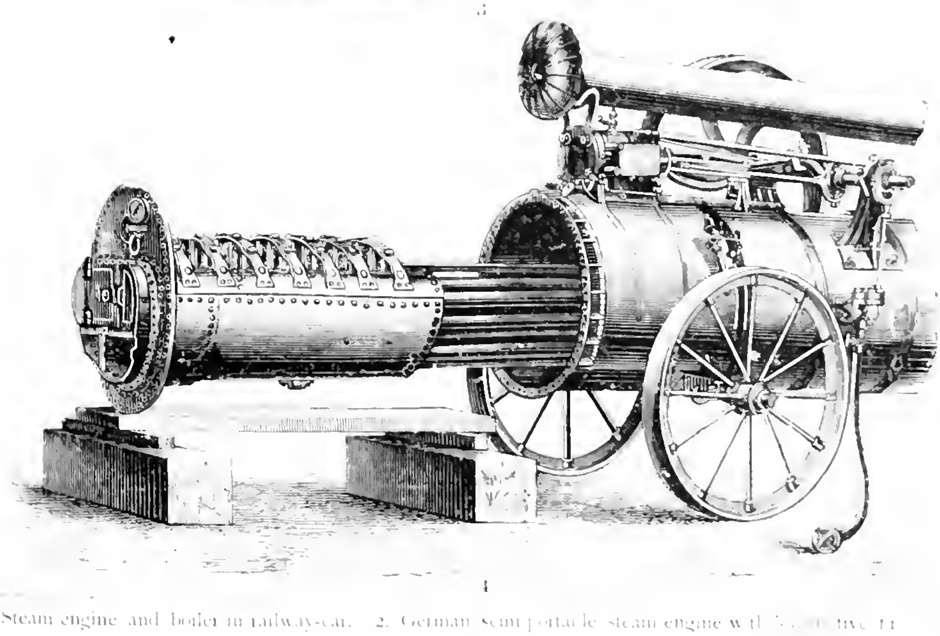
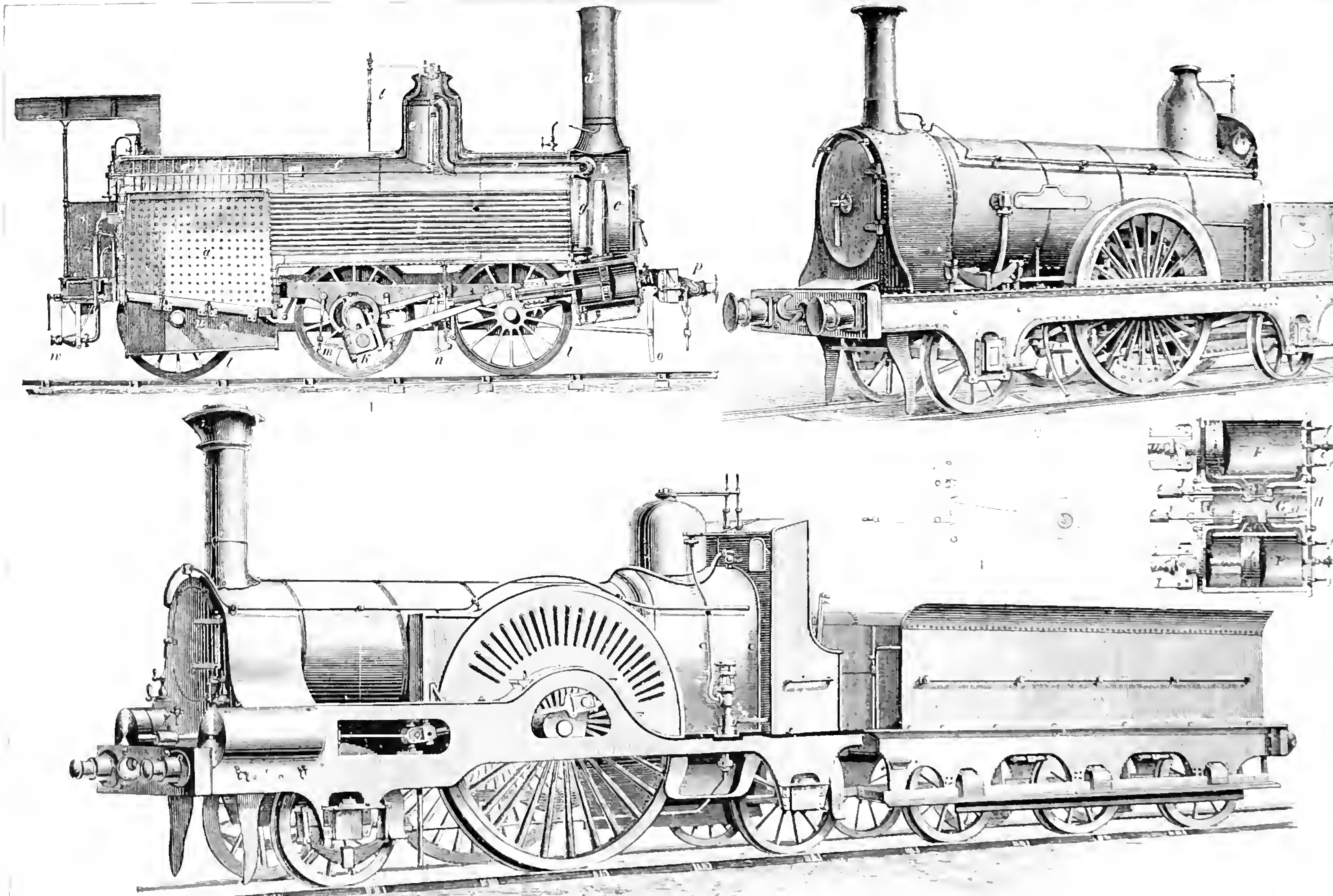
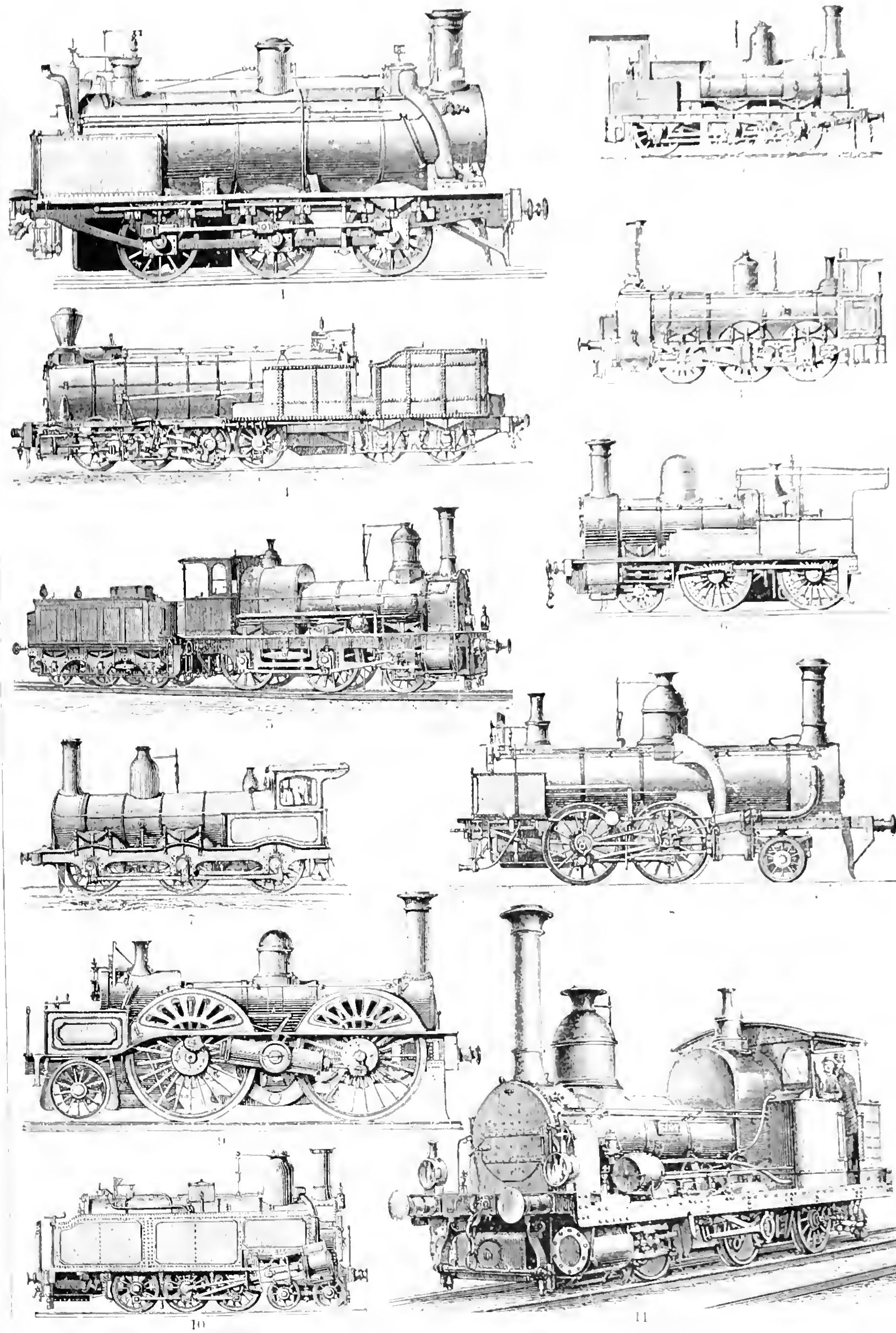


4

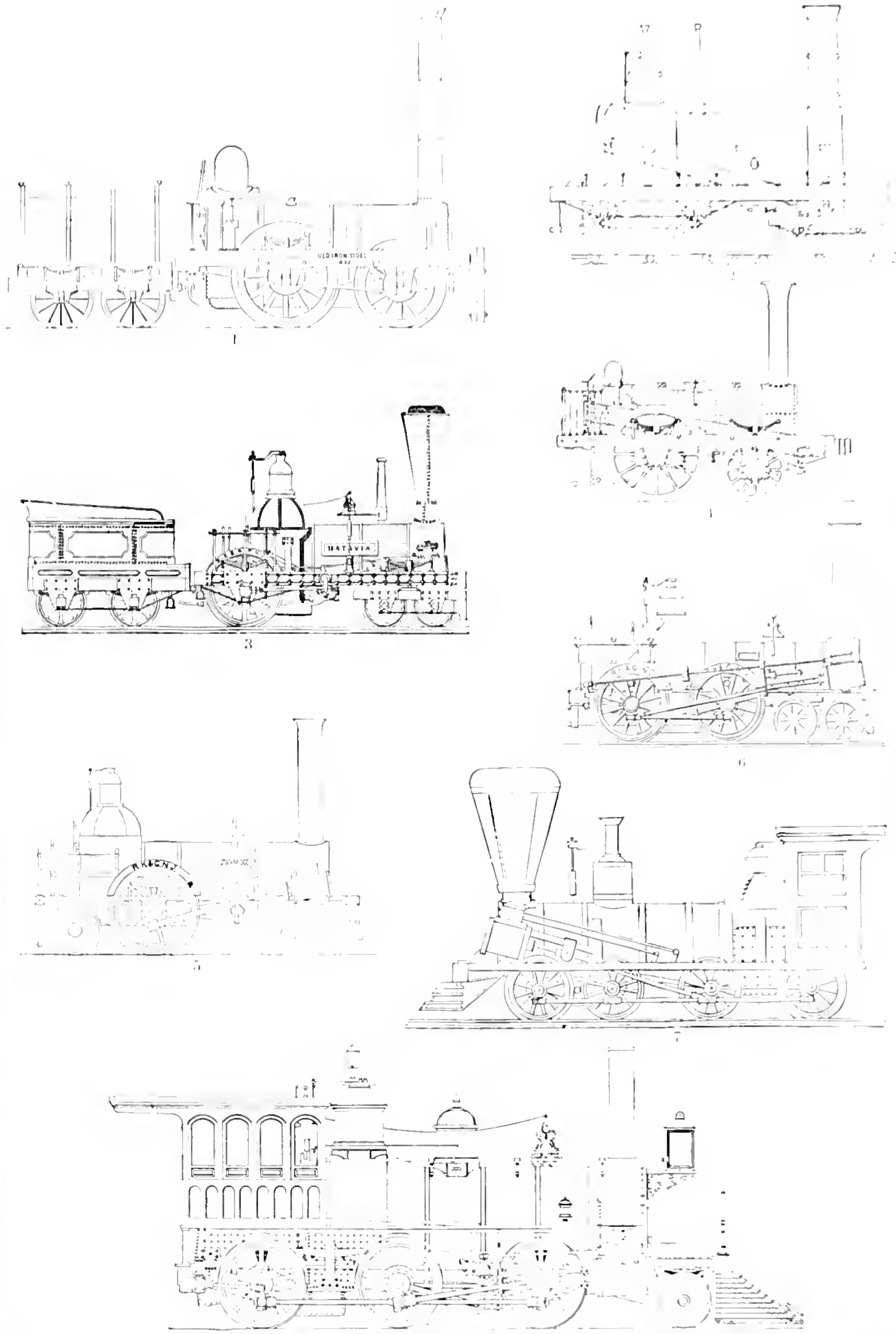
1. Steam-engine and boiler in railway-car. 2. German semi-portable steam-engine with [illegible] 3. German locomobile. 4. German locomobile with removable tubes.



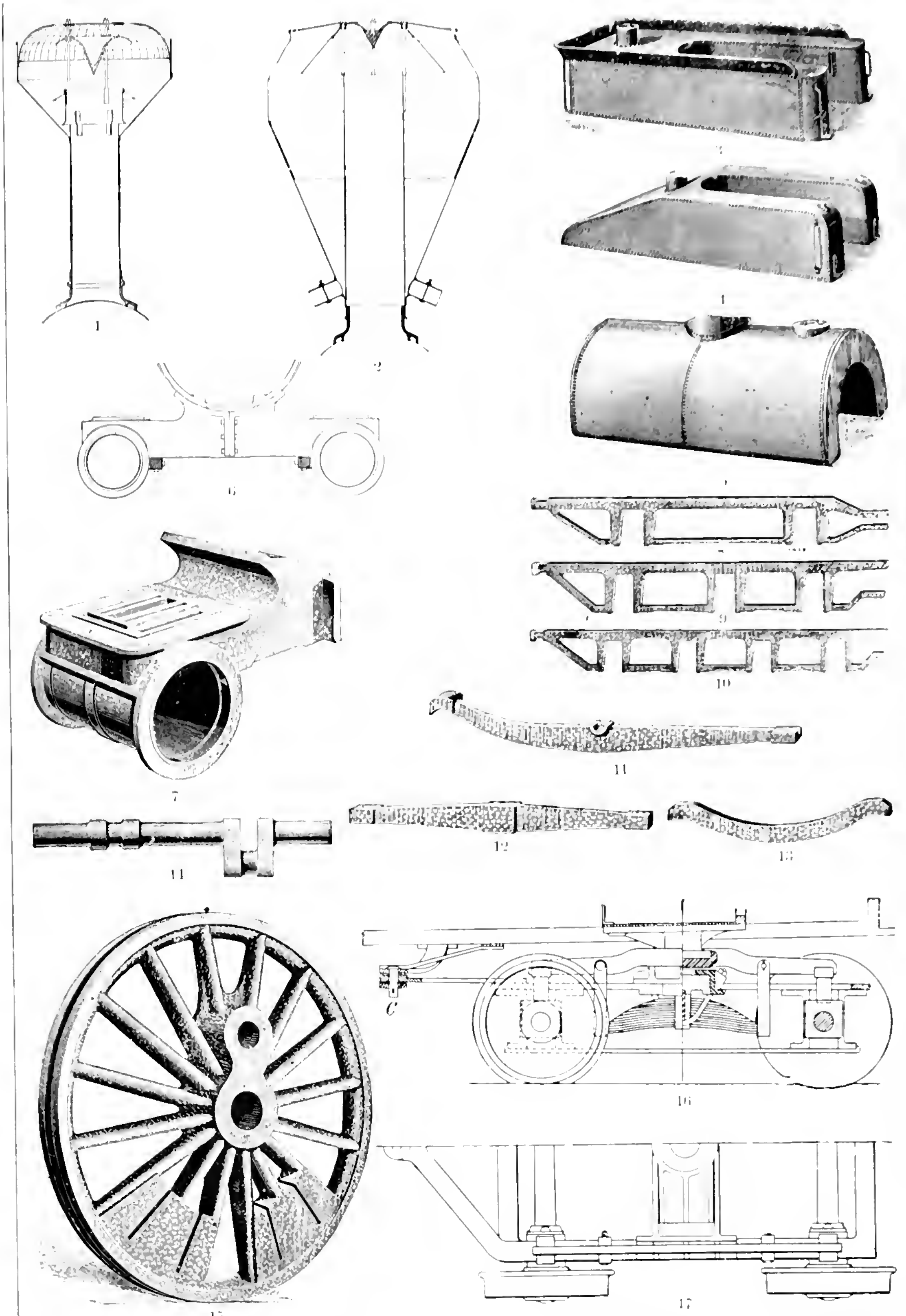
1. Longitudinal section of a Belgian locomotive. 2. Italian locomotive. 3. Caledonian locomotive for fast trains. 4. V[illegible] link motion. 5. H[illegible] section of English locomotive cylinders.



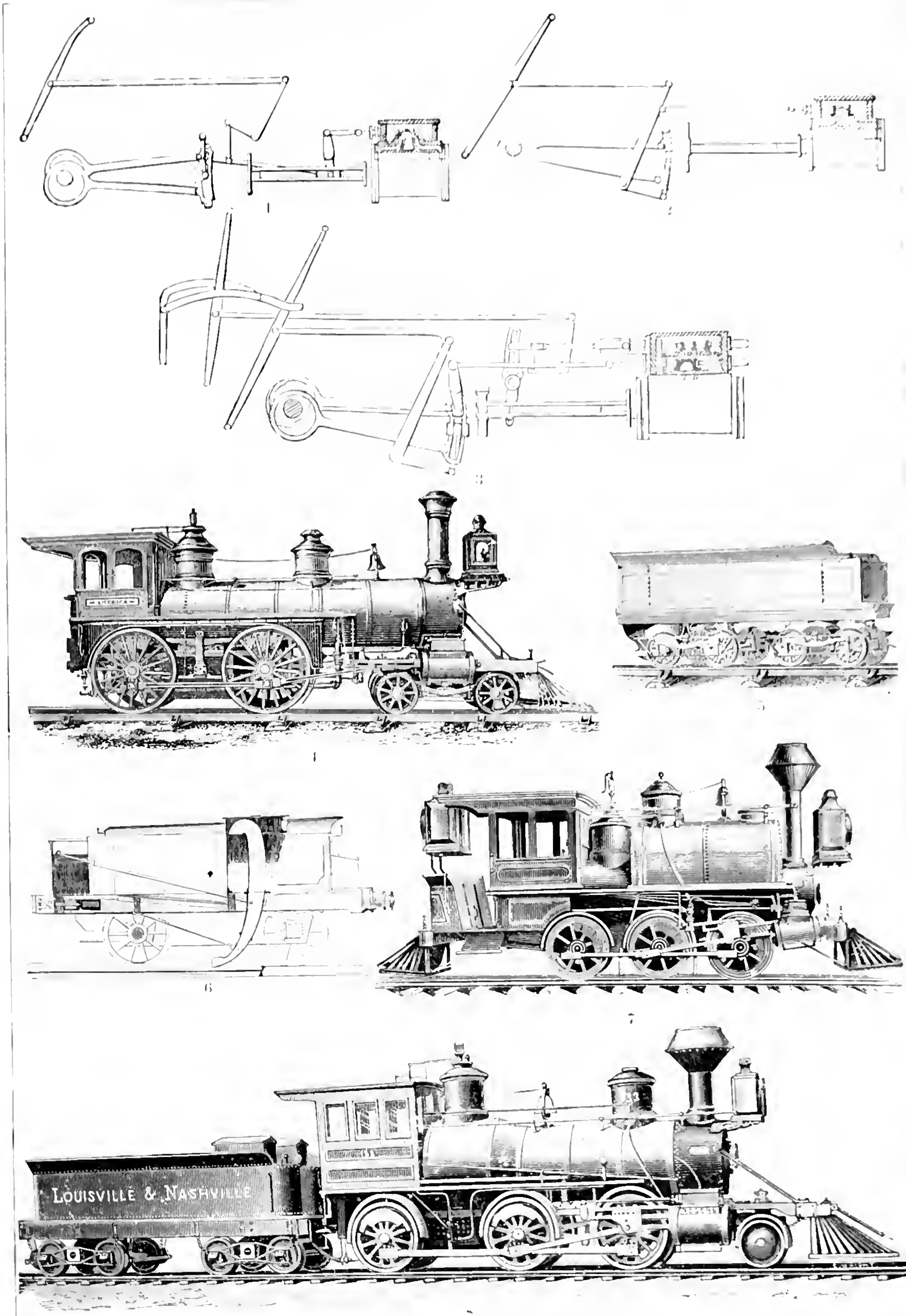
EUROPEAN LOCOMOTIVES: 1. French, 2. Belgian, 3. Russ[illegible], 4. Semmering railway, 5. [illegible], 6. East In[illegible], 7. English, 8. Mountain, 9. [illegible]'s oscillating-cylinder, 10. Freight, and 11. [illegible] locomotives.



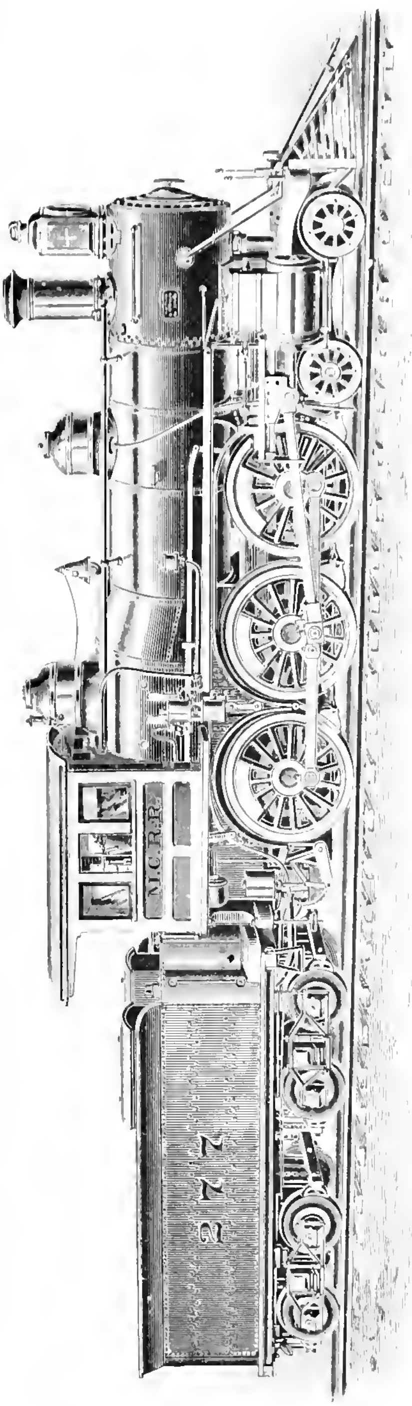
1. "Old Ironsides" (1832), 2. Campbell's (1836), 3. Bury's (1838), 4. "Planet" (1838), 5. "St. George" (1842), 6. Rogers's (1844), 7. Baldwin's (1846), and 8. "Mogul" (1863), locomotives.

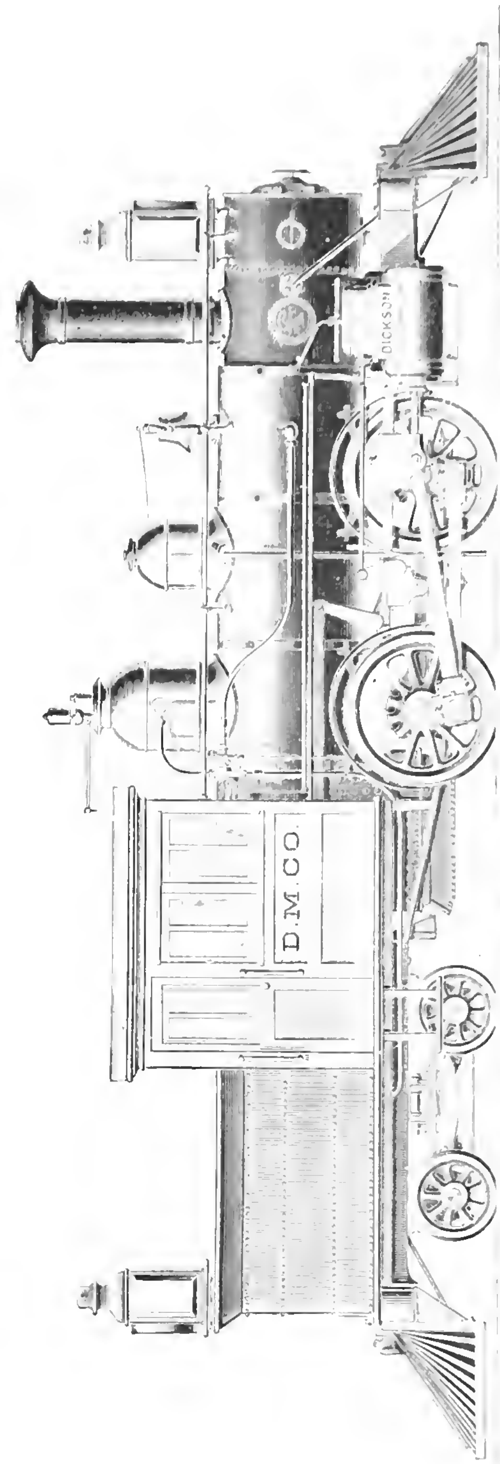


1. Smoke-stack and spark-arrester for wood-burning locomotives. 2. Smoke-stack and spark-arrester for [illegible] locomotives (Rogers Locomotive Works, Newark, N. J.). 3-5. LOCOMOTIVE TANKS: 3. Tank for separate tender. 4. Sloping tank for separate tender of switching engines. 5. Saddle-tank (Dickson Manufacturing Co., Scranton, Pa.). 6. Locomotive cylinders (1871, Rogers Locomotive Works). 7. Locomotive cylinder (Dickson Manufacturing Co.). 8. Frame of "American" type. 9. Frame of "Mogul" type. 10. Frame of "Consolidation" type, of American locomotives. 11. Pony truck. 12. Main truck. 13. Truck, equalizing levers (Dickson Manufacturing Co.). 14. Cranked driving axle. 15. Driving wheel (Dickson Manufacturing Co.). 16. Side elevation, 17. Plan, of the Bissell four-wheel locomotive truck (1857, Rogers Locomotive Works).

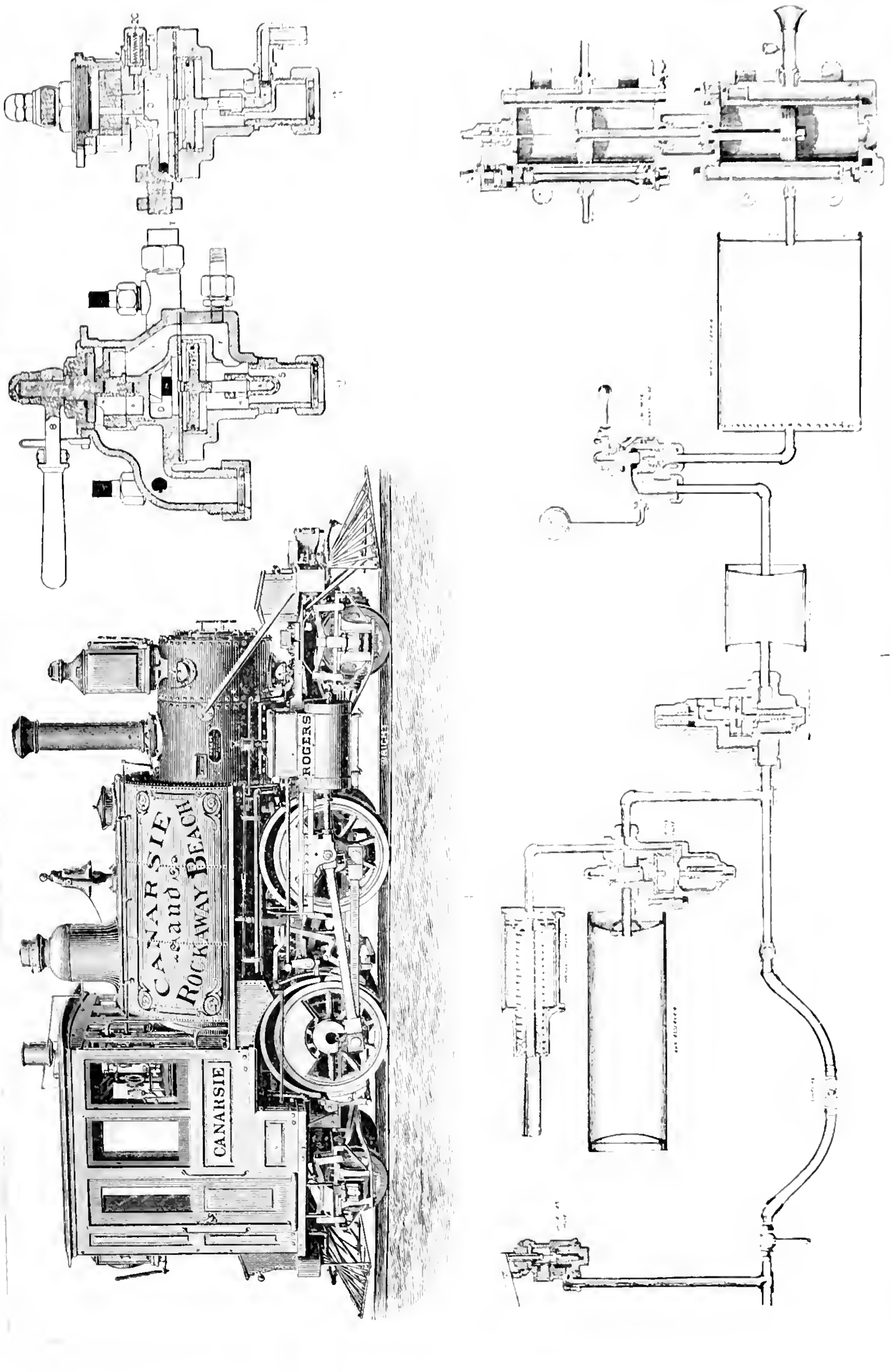


1. Rogers suspended link-motion (1849). 2. Rogers shifting link-motion (1850). 3. [illegible] n with automatic cut-off valve (1854). 4. American locomotive. 5. American locomotive tender. 6. [illegible] ing tank. 7. Six-wheel connected tank-locomotive. 8. "Consolidation" locomotive.

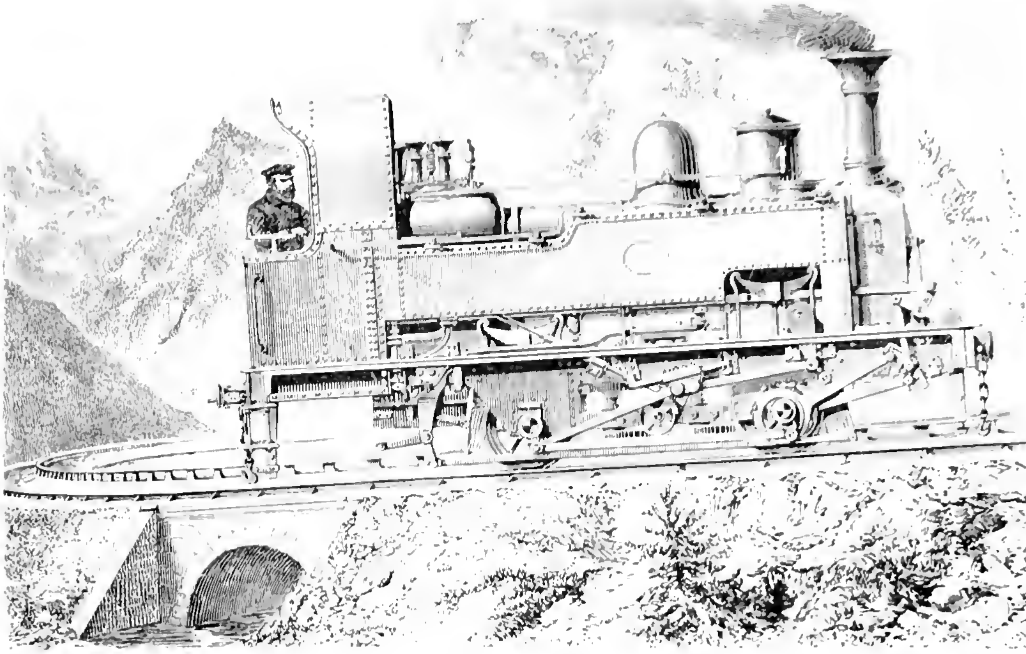




1. Ten-wheeled fast passenger-train locomotive of the Maine Central Railroad (Schenectady N. Y. Locomotive Works). 2. [illegible] Manufacturing Co., Scranton, Pa.



1. Hudson's "double ender" engine (Rogers Locomotive Works, Paterson, N.J.). 2, 3. Engineer's brake and equalizing discharge valve. 4. Westinghouse air-brake.



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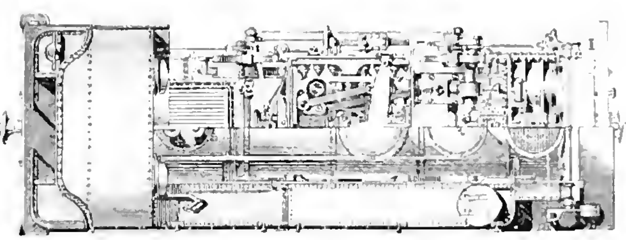

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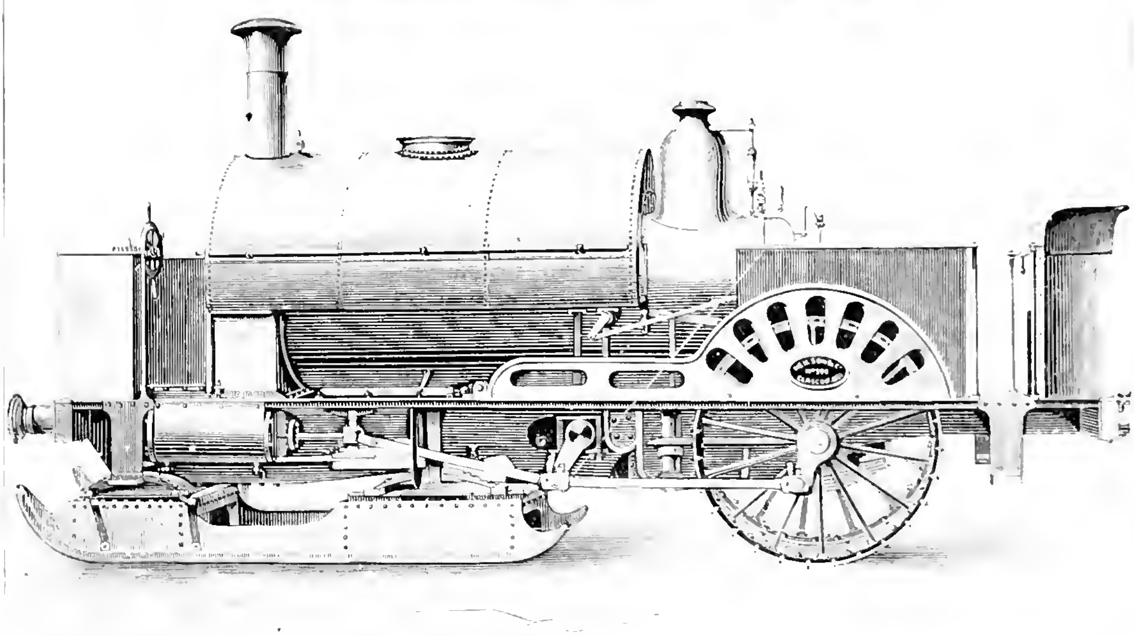

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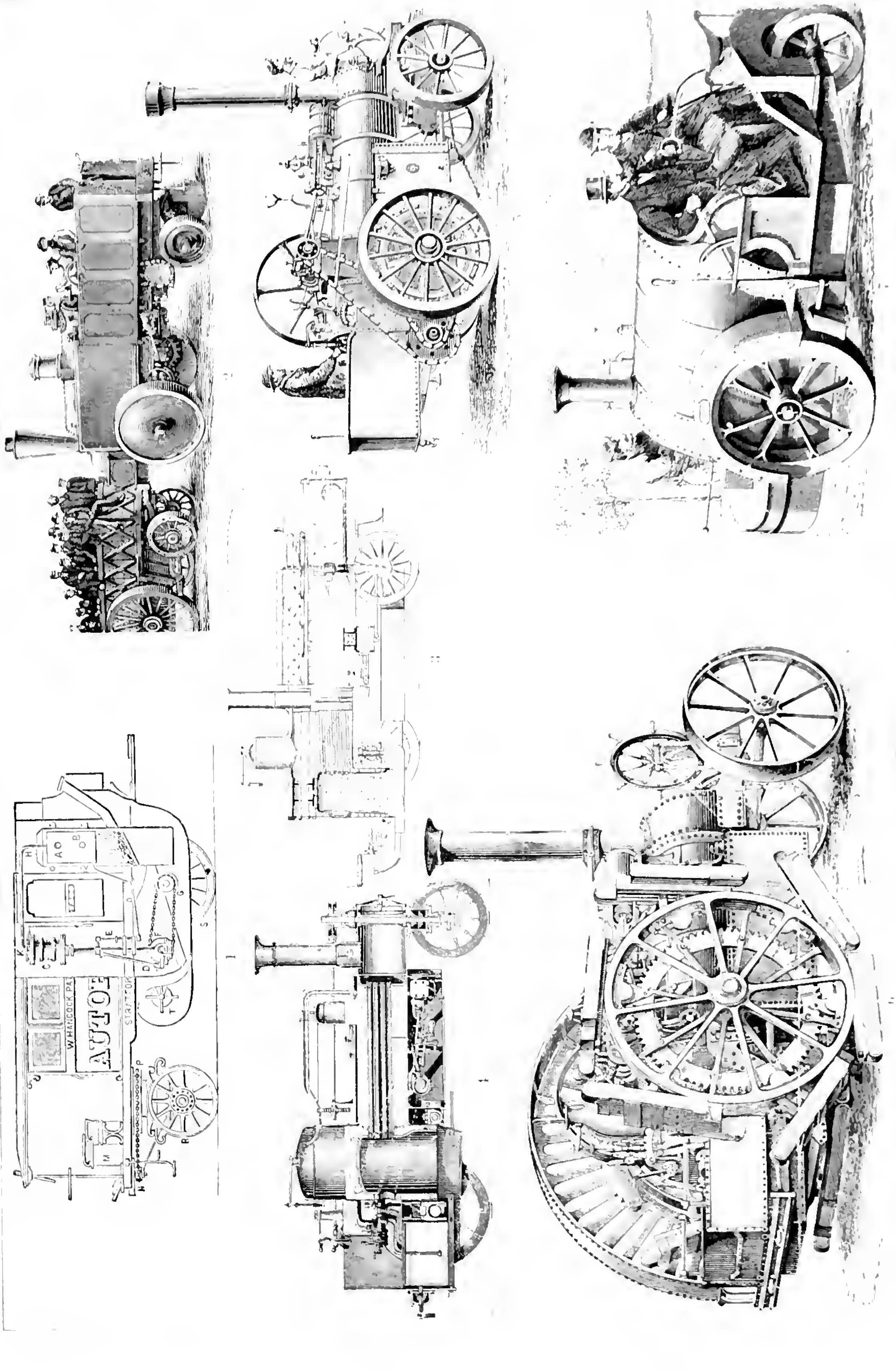
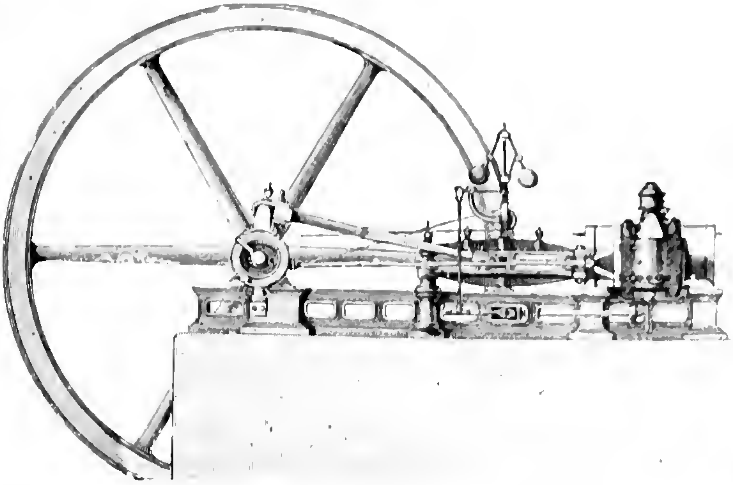
1. Perspective, 2. Upper and under half views of Fell's mountain railway locomotive. 3. Lo[illegible]



1. Hancock's steam coach "Autopsy" (1833). 2. Traction engine for ordinary streets or roads. 3. Longitudinal section and [illegible] of a traction engine. 5. Traction engine for ordinary streets or roads. 6. Traction engine with self-laying track, for [illegible]



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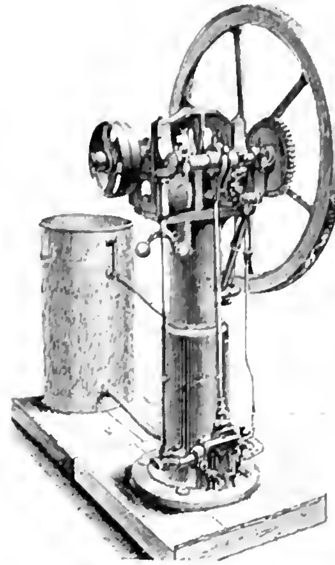

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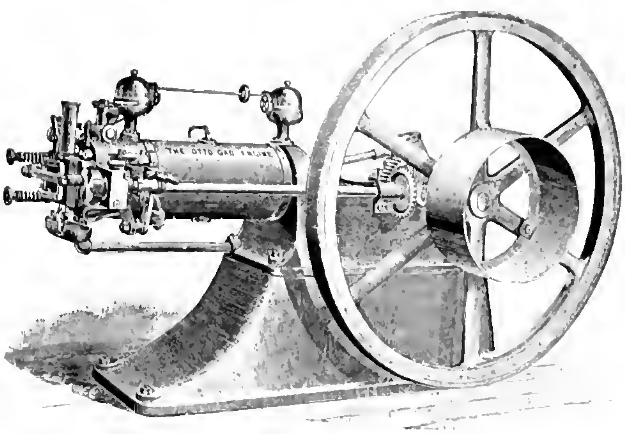

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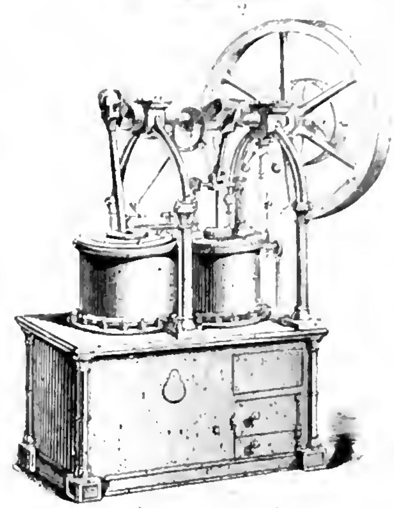

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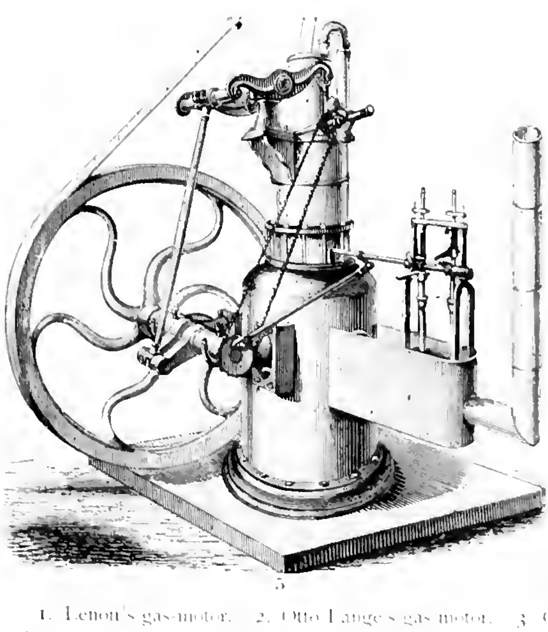

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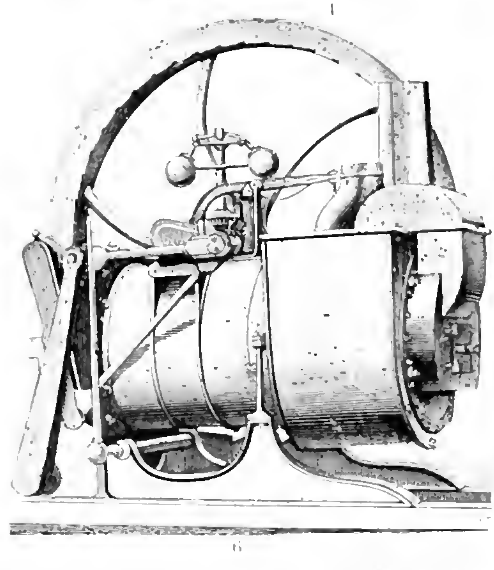
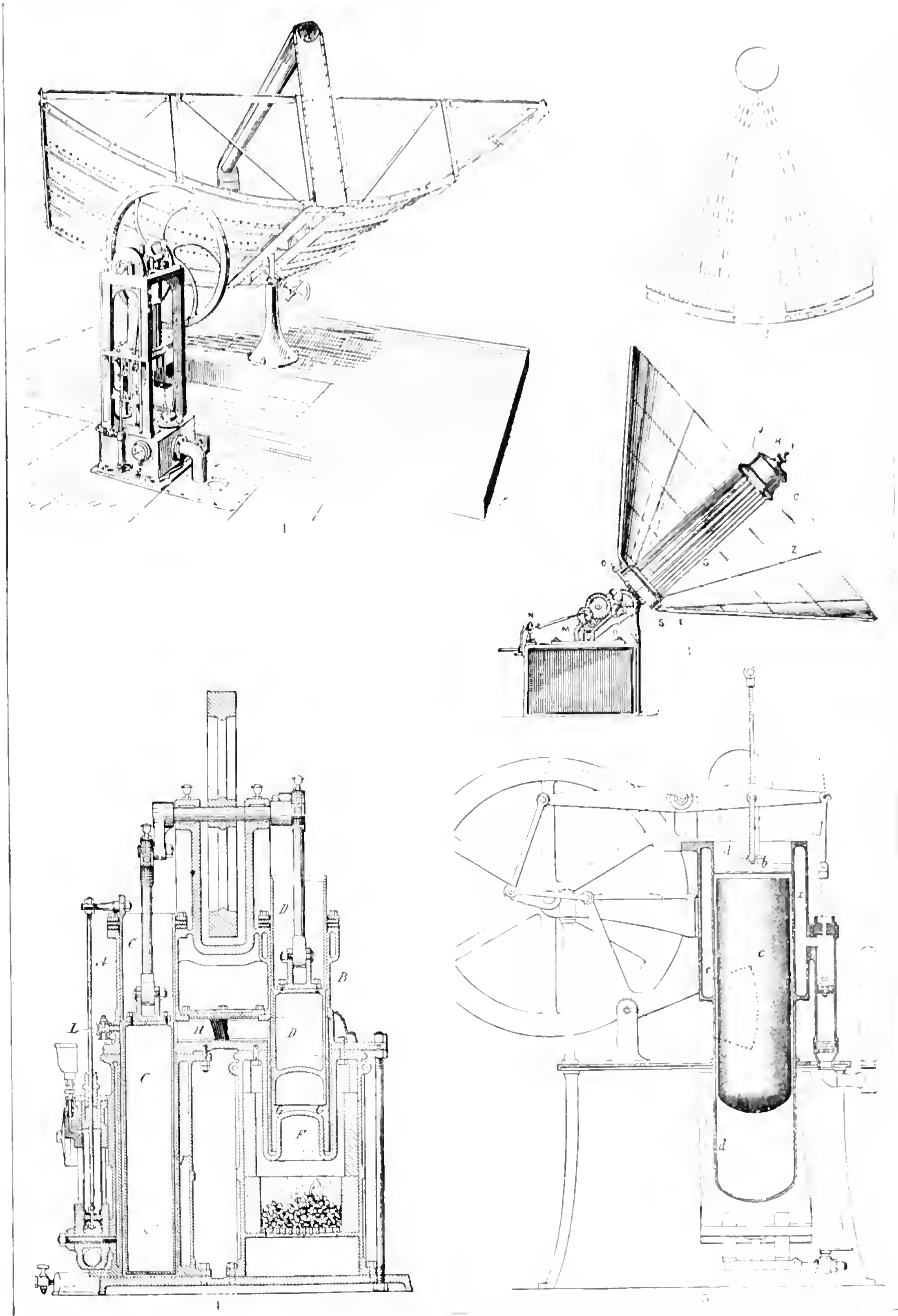
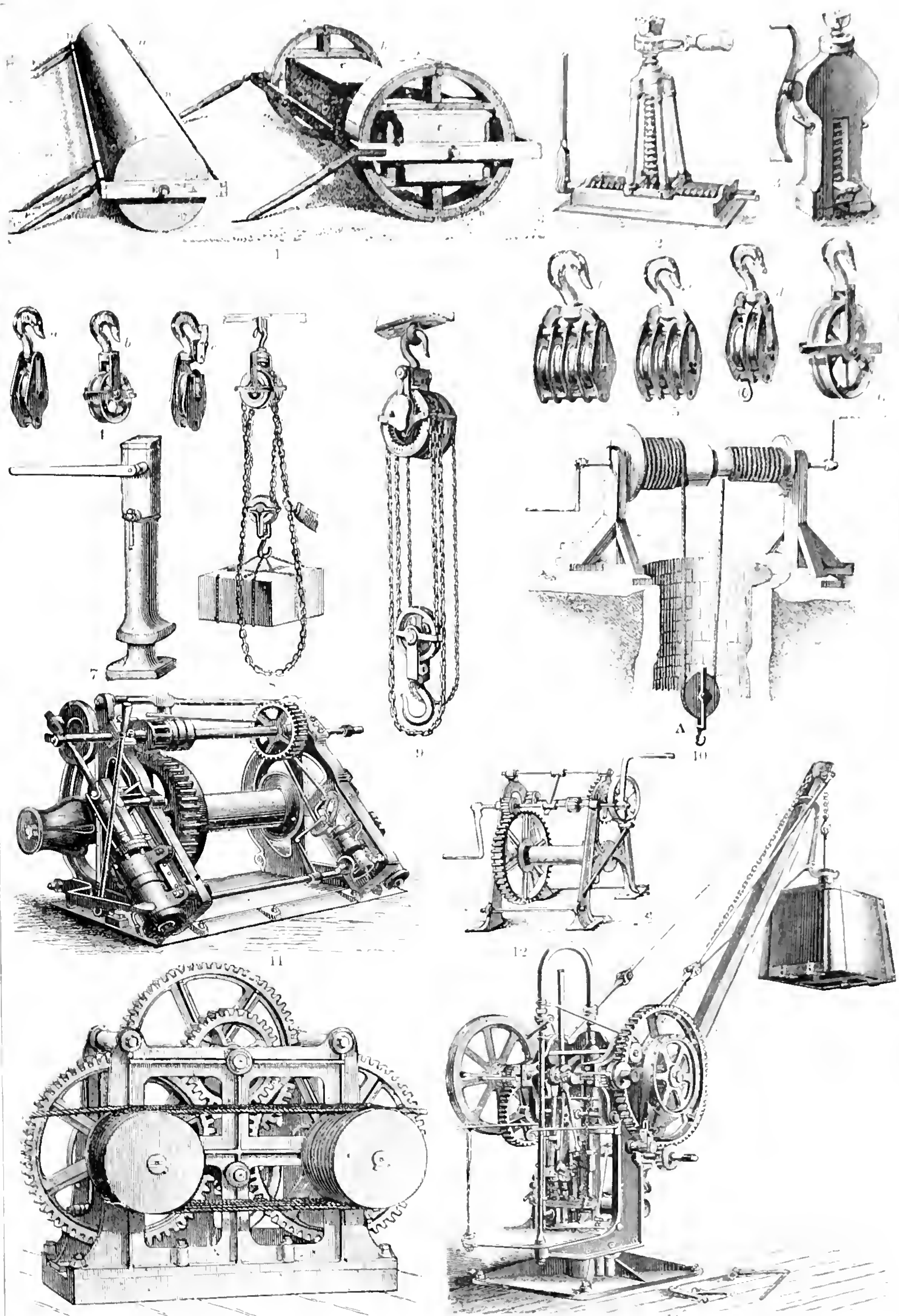


6

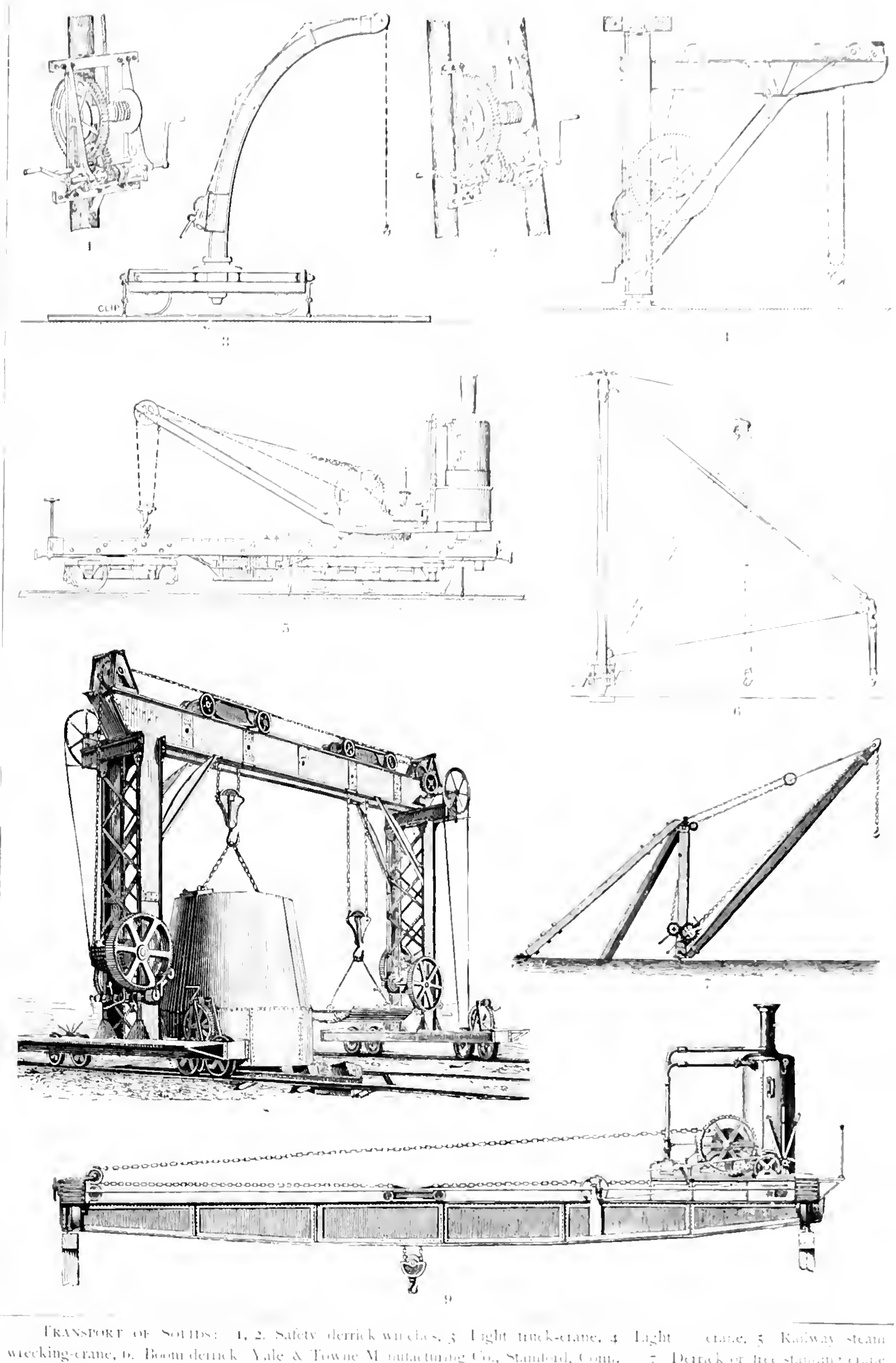
1. Lenoir's gas-motor. 2. Otto Langen's gas motor. 3. Otto horizontal gas engine (1876). 4. Wa[illegible] hot air motor. 5. Roper's hot air motor. 6. Early type of Ericsson's hot air motor.



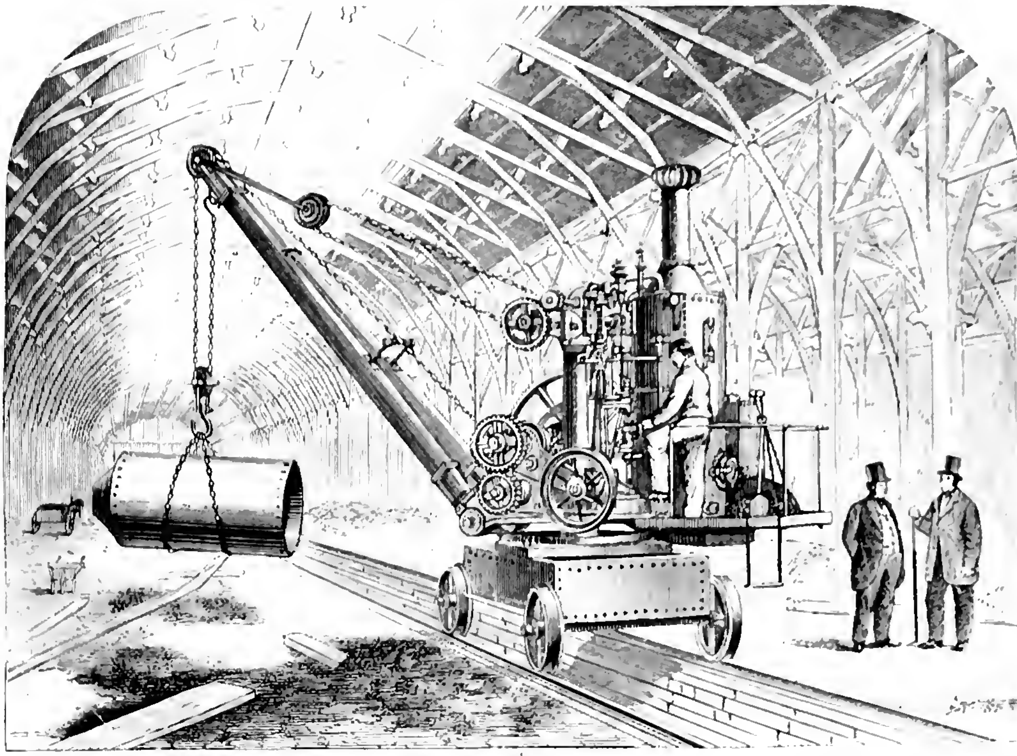
1. Perspective, 2. Section of reflector-plate, of Ericsson's sun-motor (erected in New York City in 1883). 3. Mouchot's sun engine. 4. Vertical central section of Rider's compression hot-air pumping-engine (Delamater Iron Works, N. Y.). 5. Vertical section of the latest type of Ericsson's hot-air pumping engine (Delamater Iron Works).



1. Ctesiphon's transport machines. 2. Screw- or traversing-jack. 3. W[illegible] 4. [illegible] small gin, c, snatch. 5. Wooden tackle-blocks: a, double, [illegible], triple, [illegible] 6. Iron gin block. 7. Hydraulic [illegible] 8. Differential pulley. 9. Geared differential pulley. 10. Differential or "Chinese" windlass. 11. Steam w[illegible] 12. Ordinary rope-windlass or "crab." 13. Friction-windlass. 14. Stationary steam crane.



Transport of Solids: 1, 2. Safety derrick winches. 3. Light truck-crane. 4. Light crane. 5. Railway steam wrecking-crane. 6. Boom derrick (Yale & Towne Manufacturing Co., Stamford, Conn.). 7. Derrick or free-standing crane (jib-crane). 8. Traversing crane or gantry. 9. Travelling crane.



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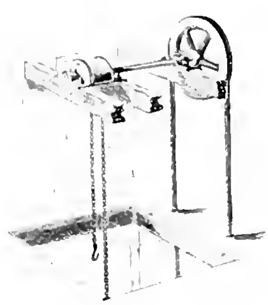

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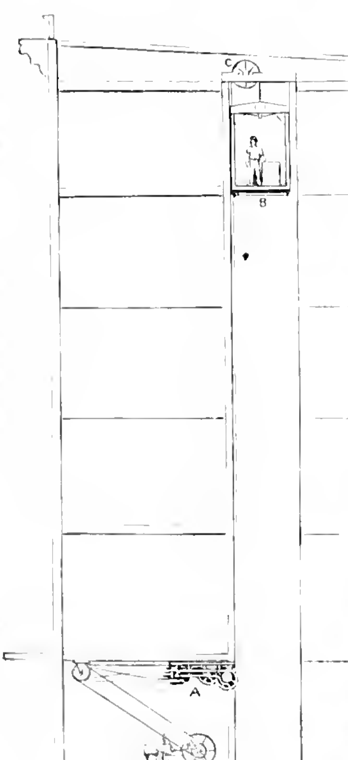

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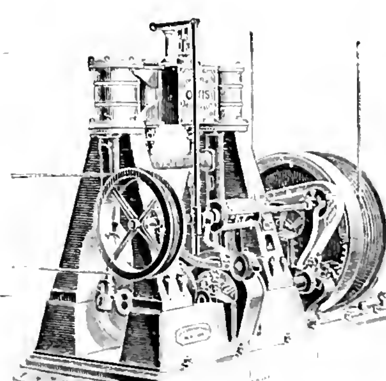

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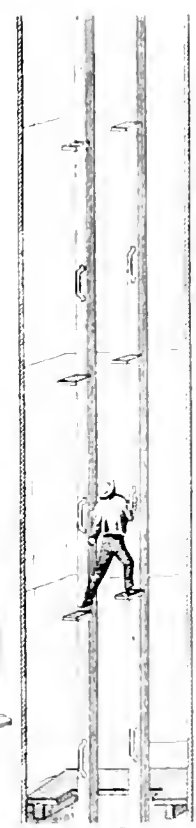

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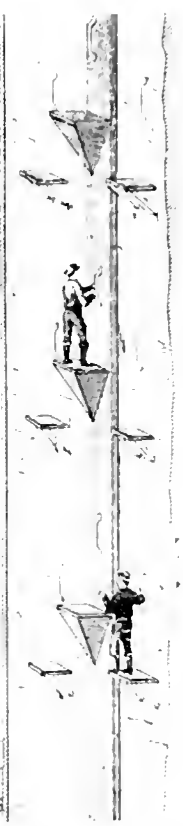
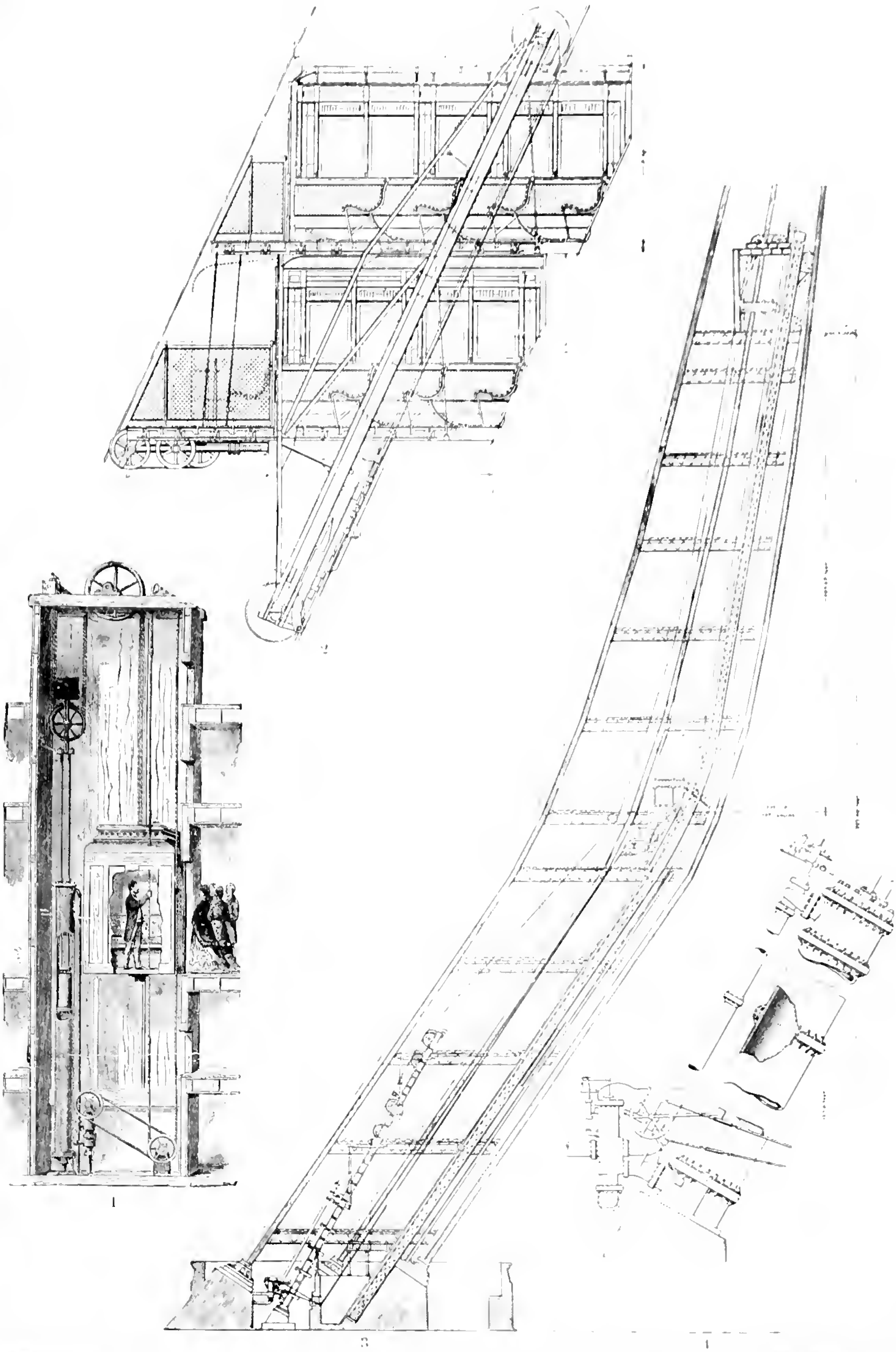
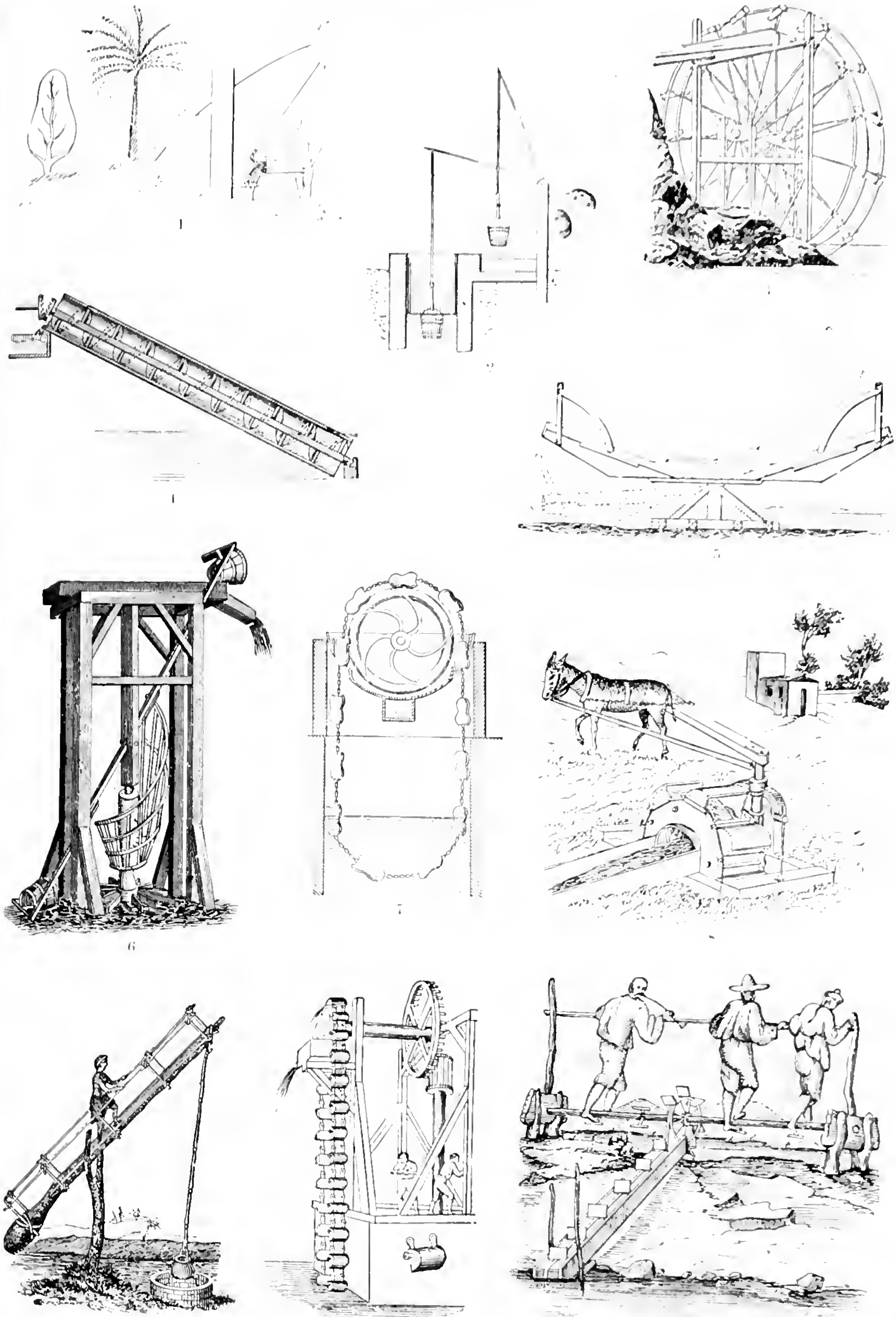


6

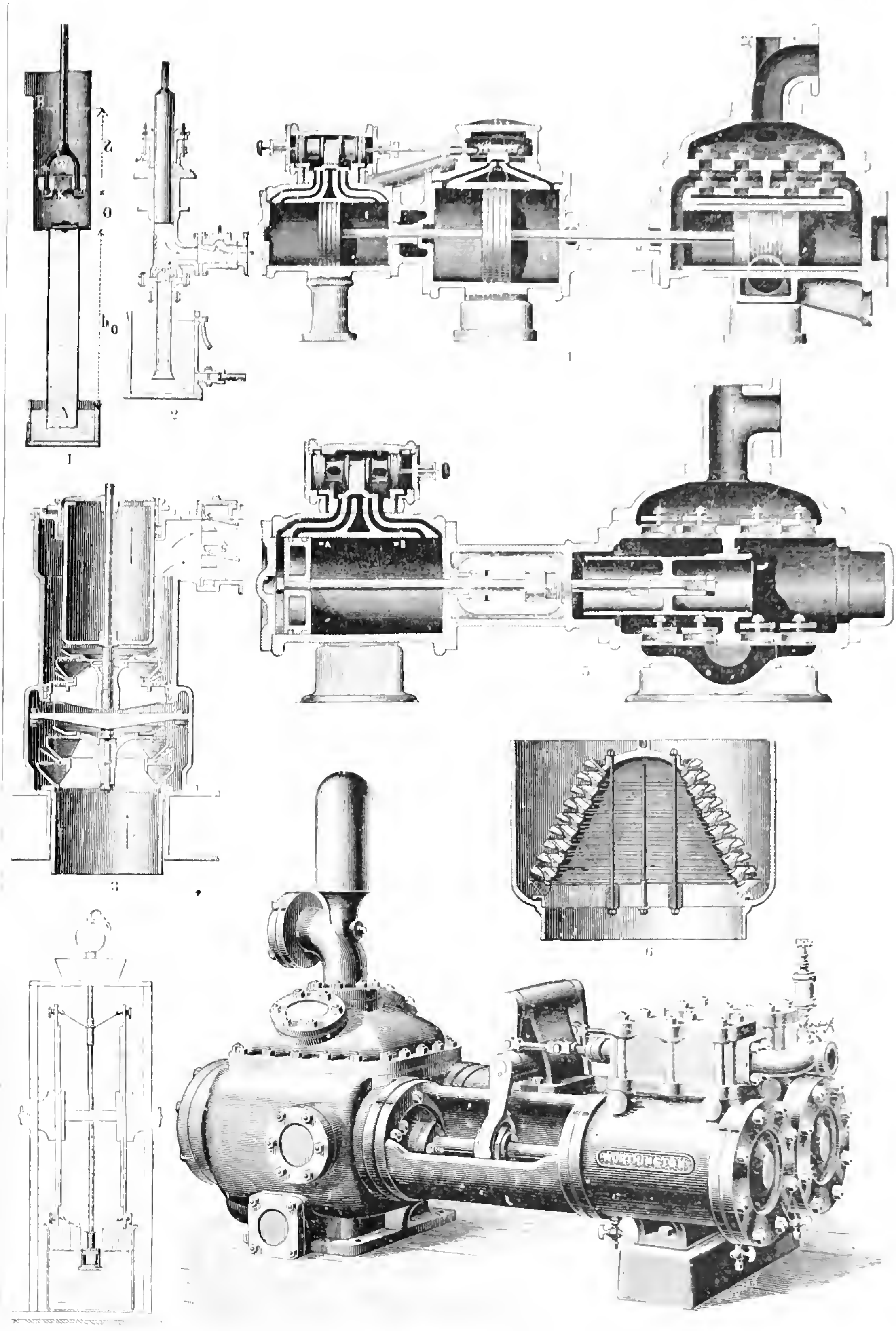
TRANSPORT OF SOLIDS:—1. Railway portable steam crane. 2. "Double-lift" safety hoist (Yale & Towne Manufacturing Co., Stamford, Conn.). 3. Platform steam elevator. 4. Hoisting engine with drum (Otis Brothers & Co., New York). 5. Double reciprocating rod man engine. 6. Single reciprocating rod man engine.



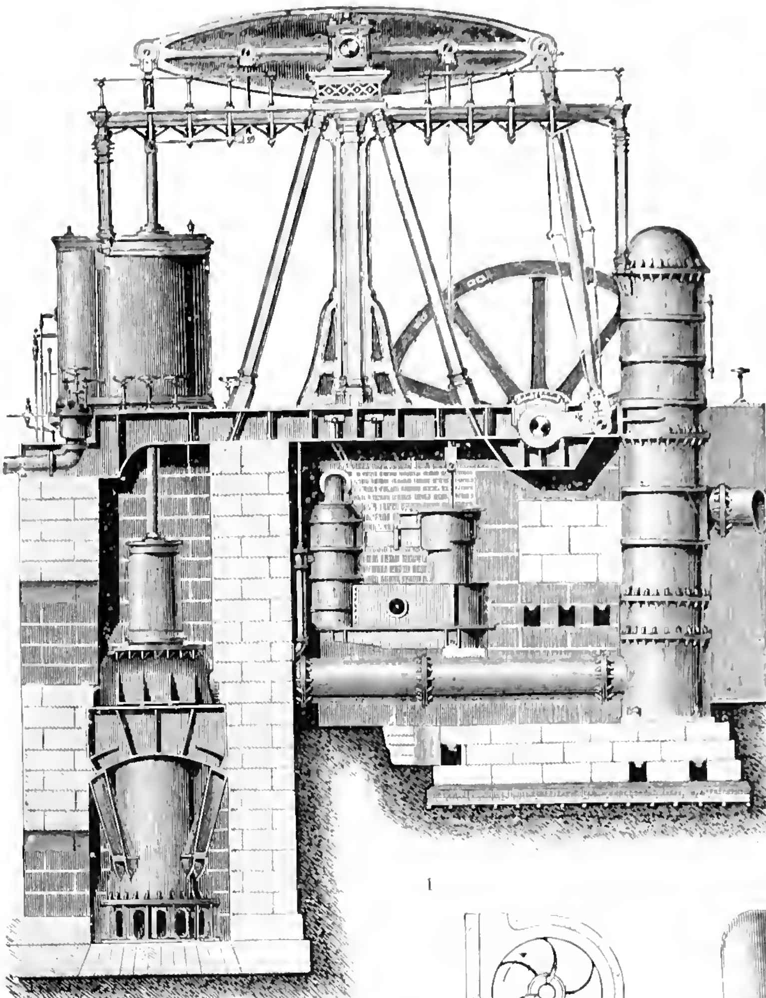
1. Hydraulic passenger elevator (Otis Brothers & Co., New York). 2. Vertical section of car and frame of the Eiffel Tower passenger elevator (Otis Brothers & Co.). 3. Section of one leg of the Eiffel tower, showing arrangement of truss construction, hydraulic machine, and elevator car. 4. Hydraulic cylinder.



TRANSPORT OF LIQUIDS:—1. Egyptian shadoof. 2. Modern Egyptian shadoof or swape. 3. Noria or bucket wheel. 4. Archimedean screw. 5. Bascule. 6. Swape. 7. Bucket wheel. 8. Eastern bucket wheel. 9. Hindu Picotah. 10. Chain of pots. 11. Chinese chain-pump.



TRANSPORT OF LIQUIDS:—1. Single acting valved piston suction pump. 2. Single acting [illegible] 3. Differential pump. 4. Compound direct acting duplex piston pump (Hall Steam pump Co., New York). 5. [illegible] plunger-pump (Hall Steam pump Co.). 6. Gill valve. 7. Cane pump. 8. Worthington [illegible] (Henry R. Worthington, New York).



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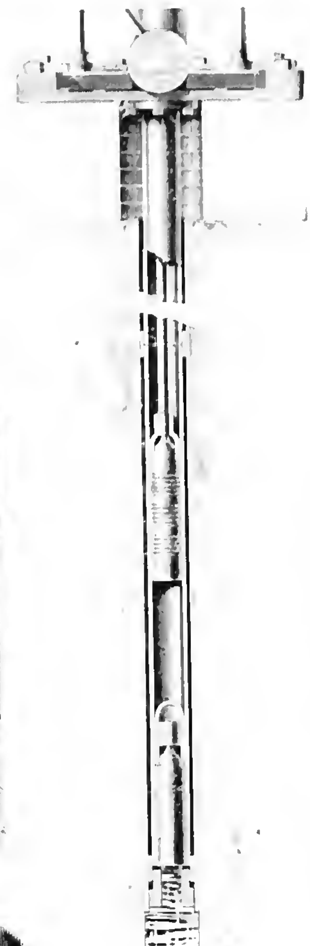

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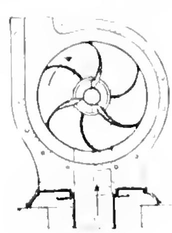

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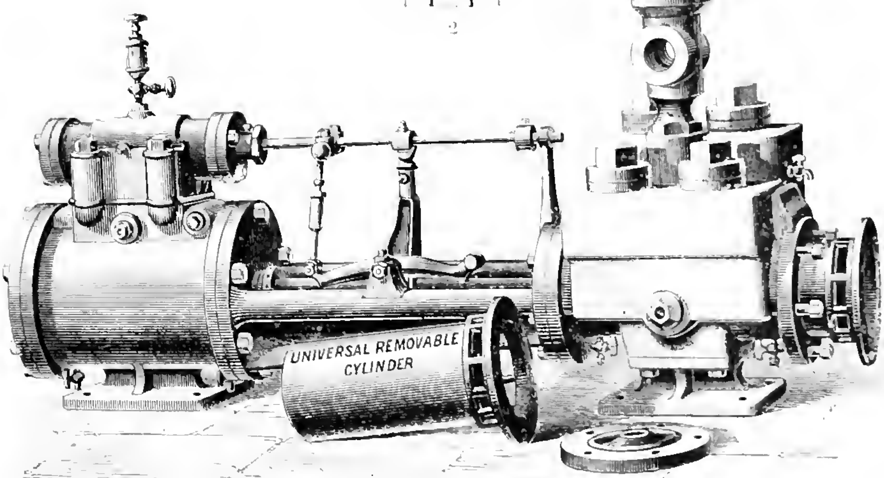
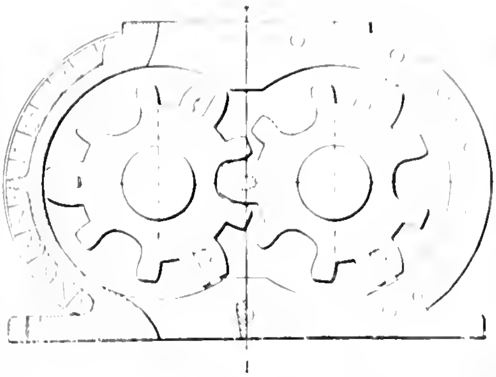


4

TRANSPORT OF LIQUIDS:— 1. Pumping-engine, Brooklyn (N. Y.) Waterworks. 2. Centrifugal pump (section). 3. Artesian-well pump. 4. Oil line pump with removable cylinder lining (Knowles Steam-pump Works, New York.



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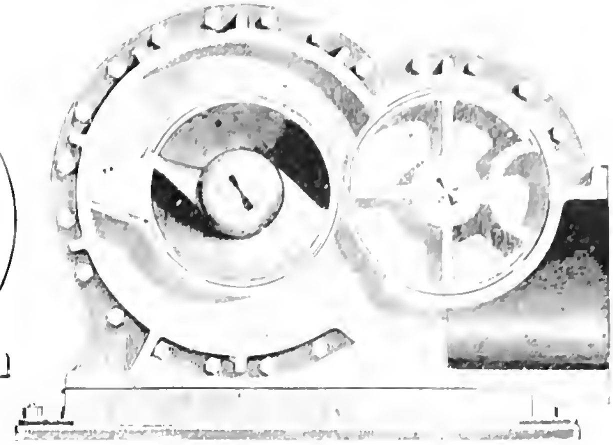

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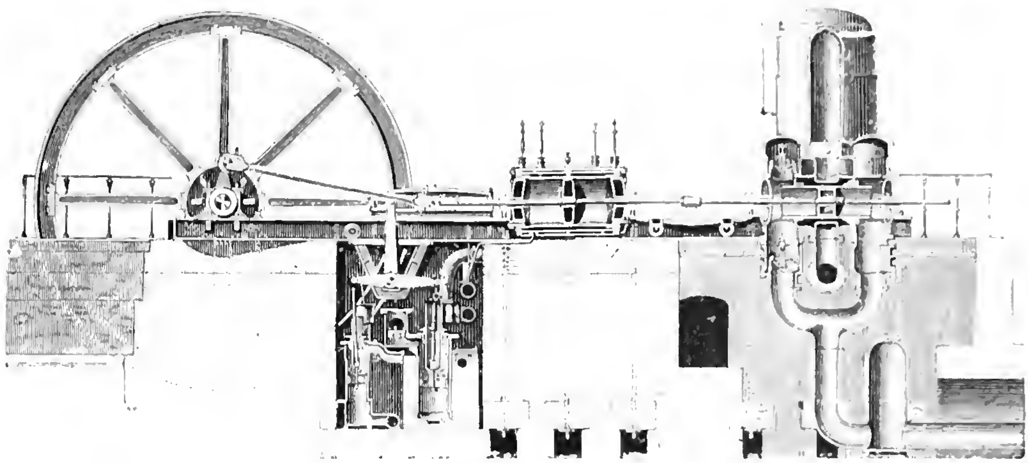

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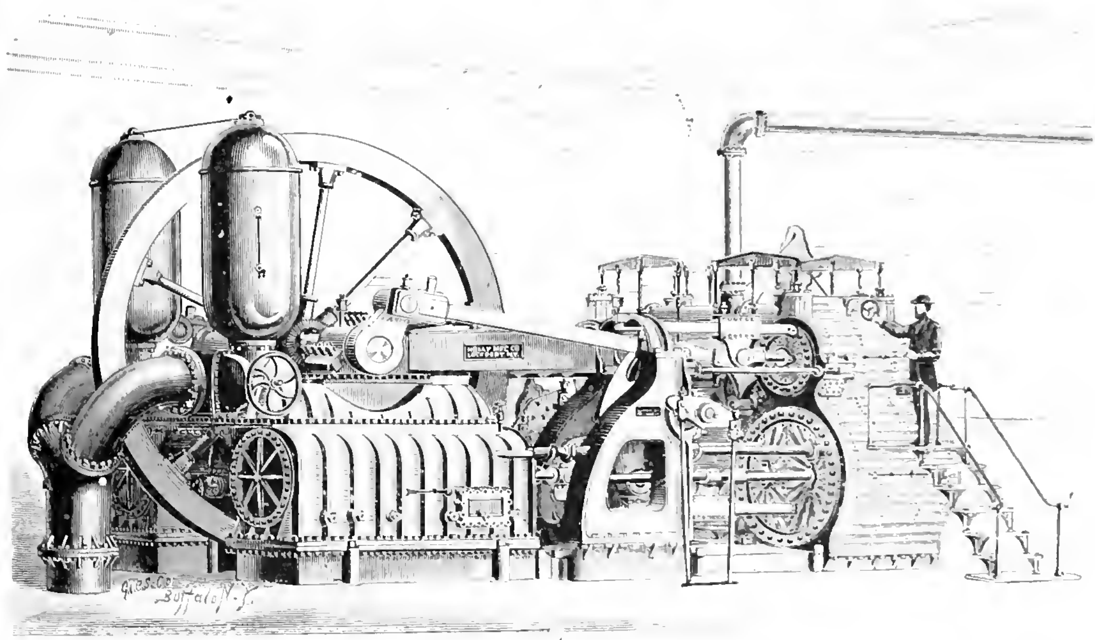

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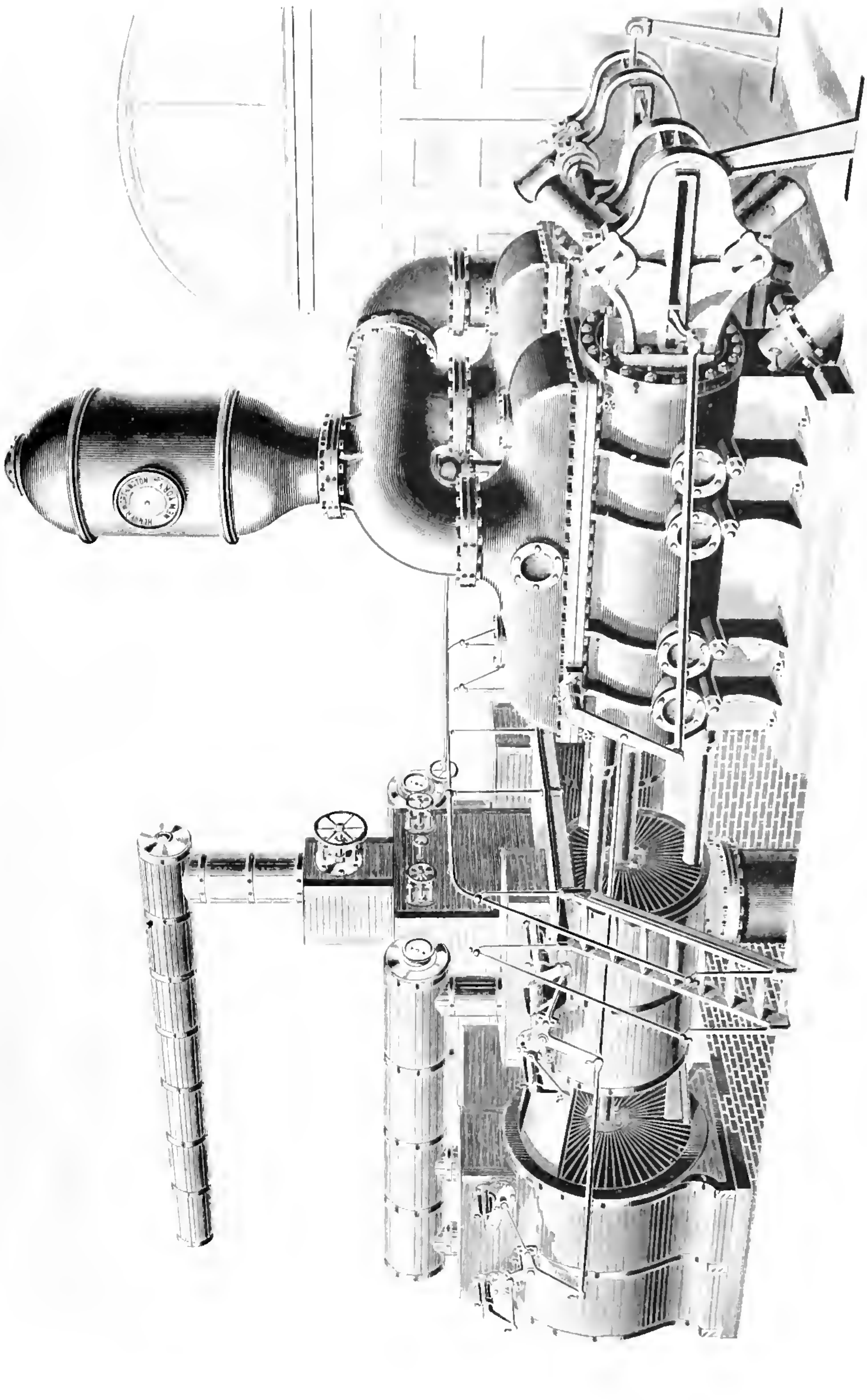
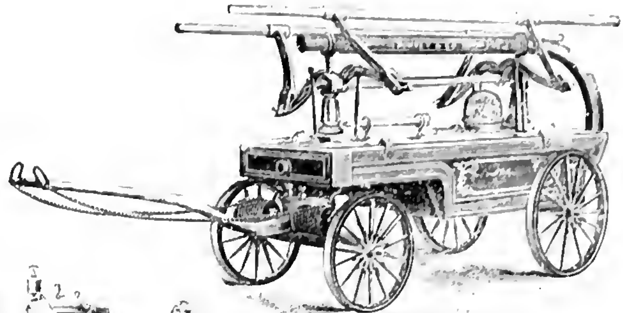
TRANSPORT OF LIQUIDS: 1. Silsby rotary-pump (Silsby Manufactur[illegible], S[illegible] F[illegible], N. Y.). 2. [illegible] piston-pump (Kensington Engine Works, Philadelphia). 3. Pumping-engine [illegible] the waterw[illegible] [illegible]. 4. Gaskill pumping-engine, Saratoga Springs, N. Y. (Holly Manufacturing Co., Lockport, N. Y.)



[illegible] Worthington high duty [illegible] engine. Henry R. W[illegible] New Y[illegible]



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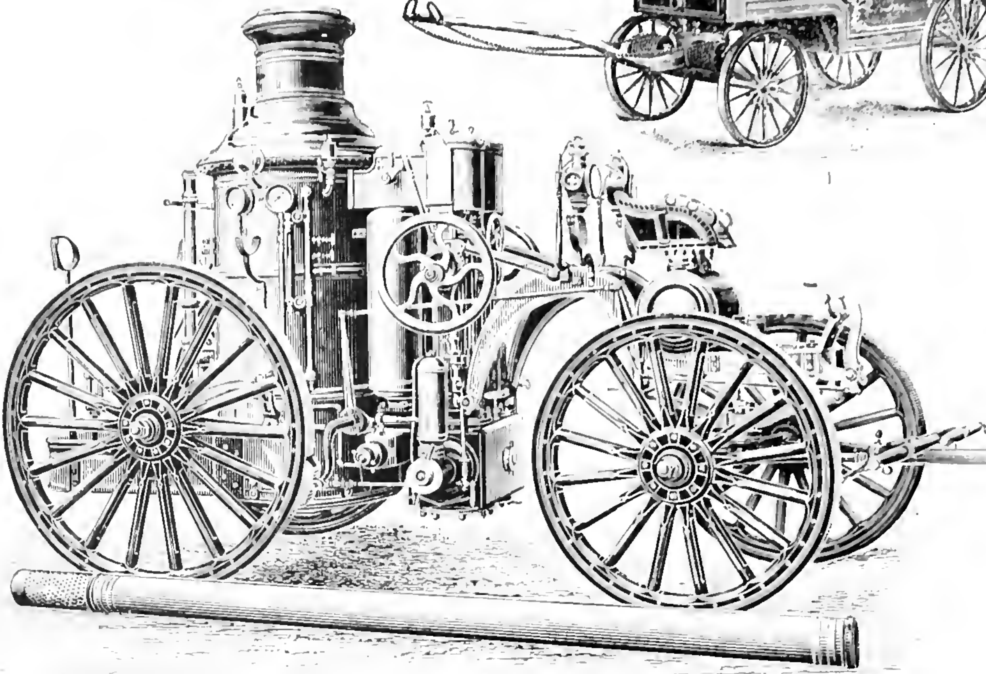

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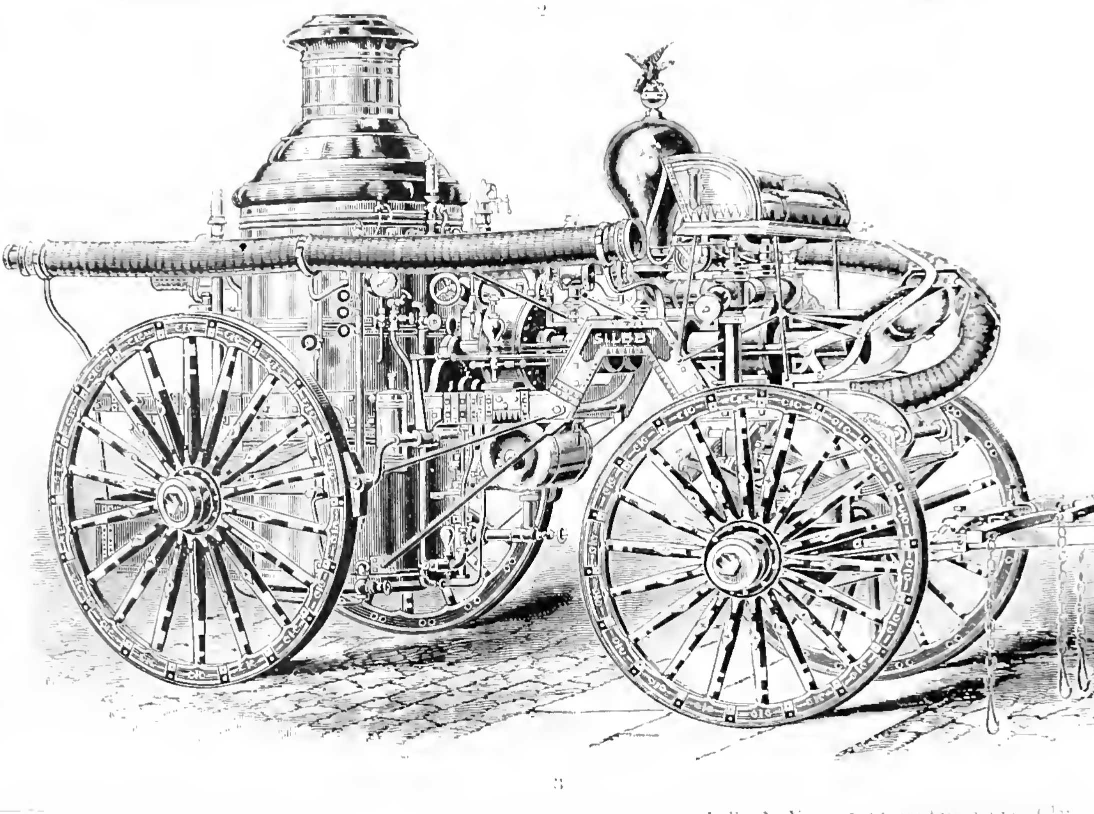

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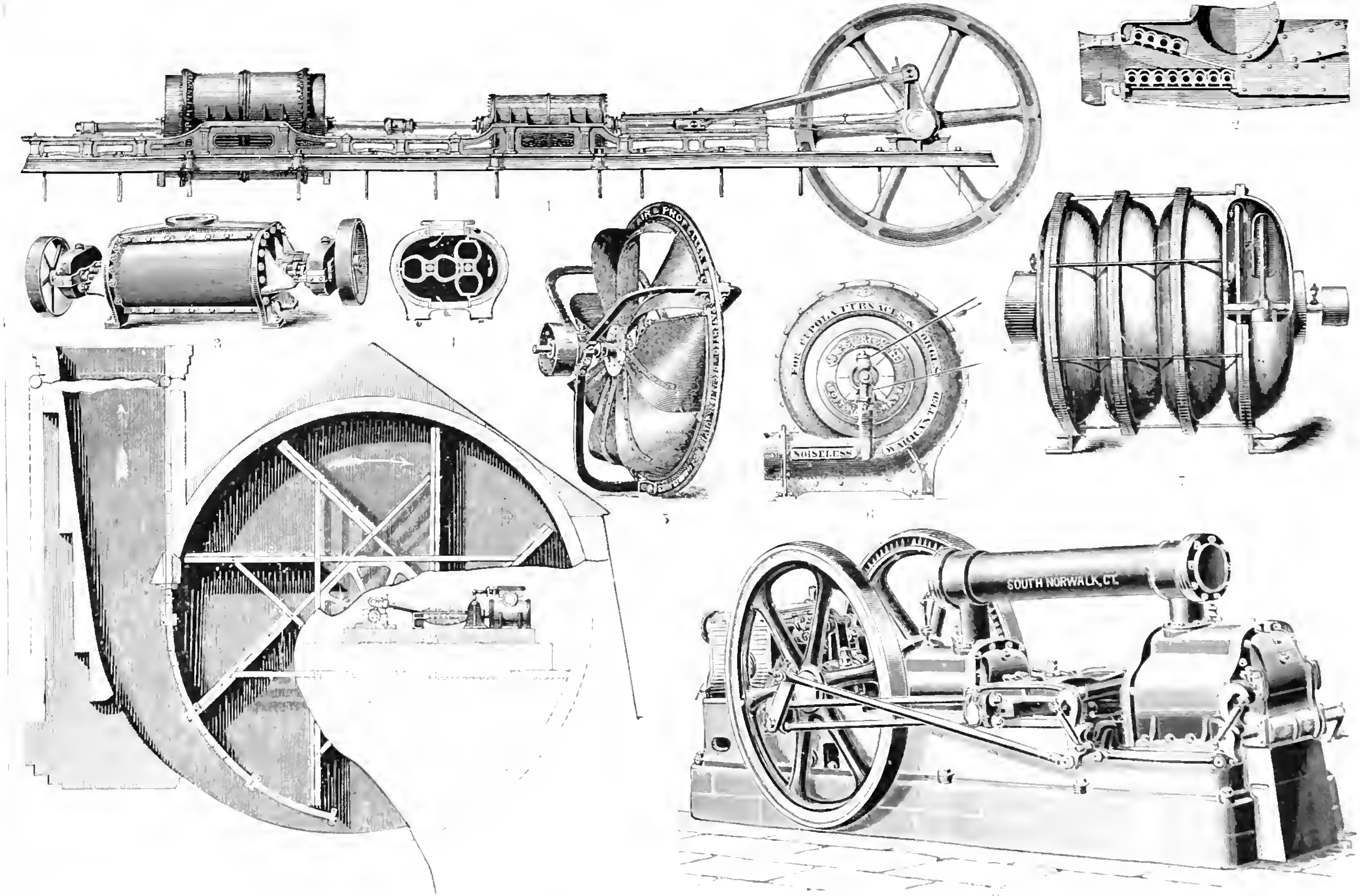
TRANSPORT OF LIQUIDS: 1. Hand fire-engine (Rumsey & Co., Seneca Falls, N.Y.). 2. Steam fire-engine (Clapp & Jones Manufacturing Co., Hudson, N.Y.). 3. Silsby rotary steam fire-engine (Silsby Manufacturing Co., Seneca Falls, N.Y.).



TRANSPORT OF GASES. 1. Horizontal cylinder blowing engine. 2. Valve of blowing engine. 3. Elevation, 4. Cross-section of Roots's system (P. H. & F. M. Roots Co., Connersville, Ind.). 5. Blackman exhaust fan and blower (Exhaust Ventilator Co., Philadelphia). 6. Sturtevant centrifugal blower (B. F. Sturtevant Co.). 7. Multiplying turbine ventilator. 8. Guibal's ventilating fan wheel. 9. Air-compressor with positive valve motion (Norwalk Iron Works, South Norwalk, Conn.).

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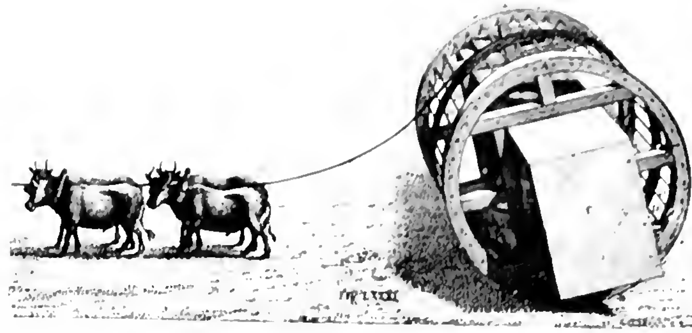

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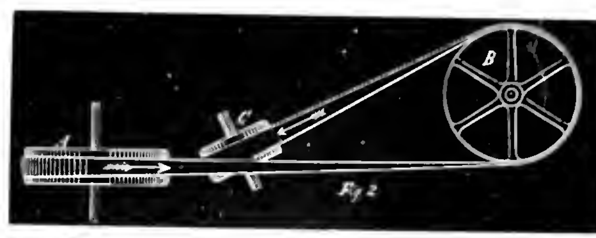

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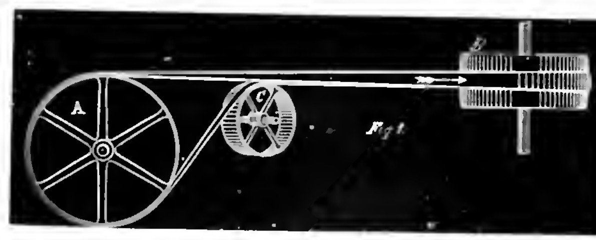

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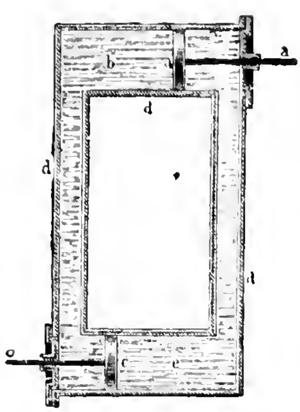

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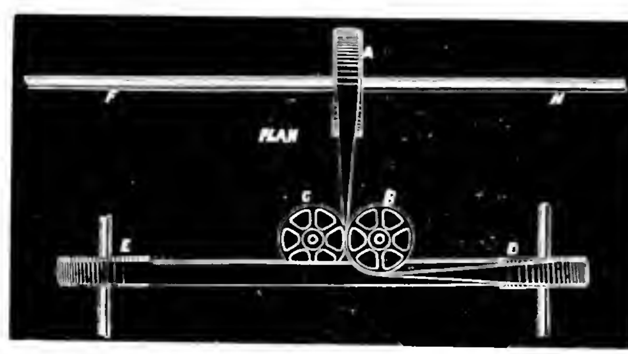

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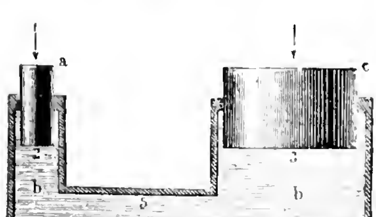

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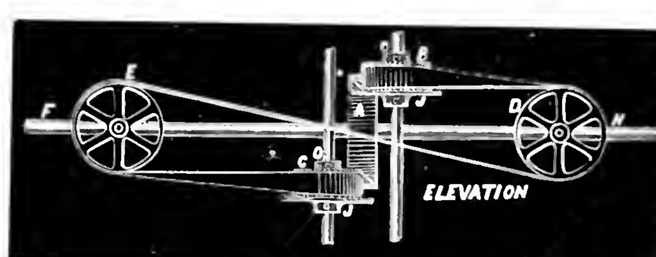
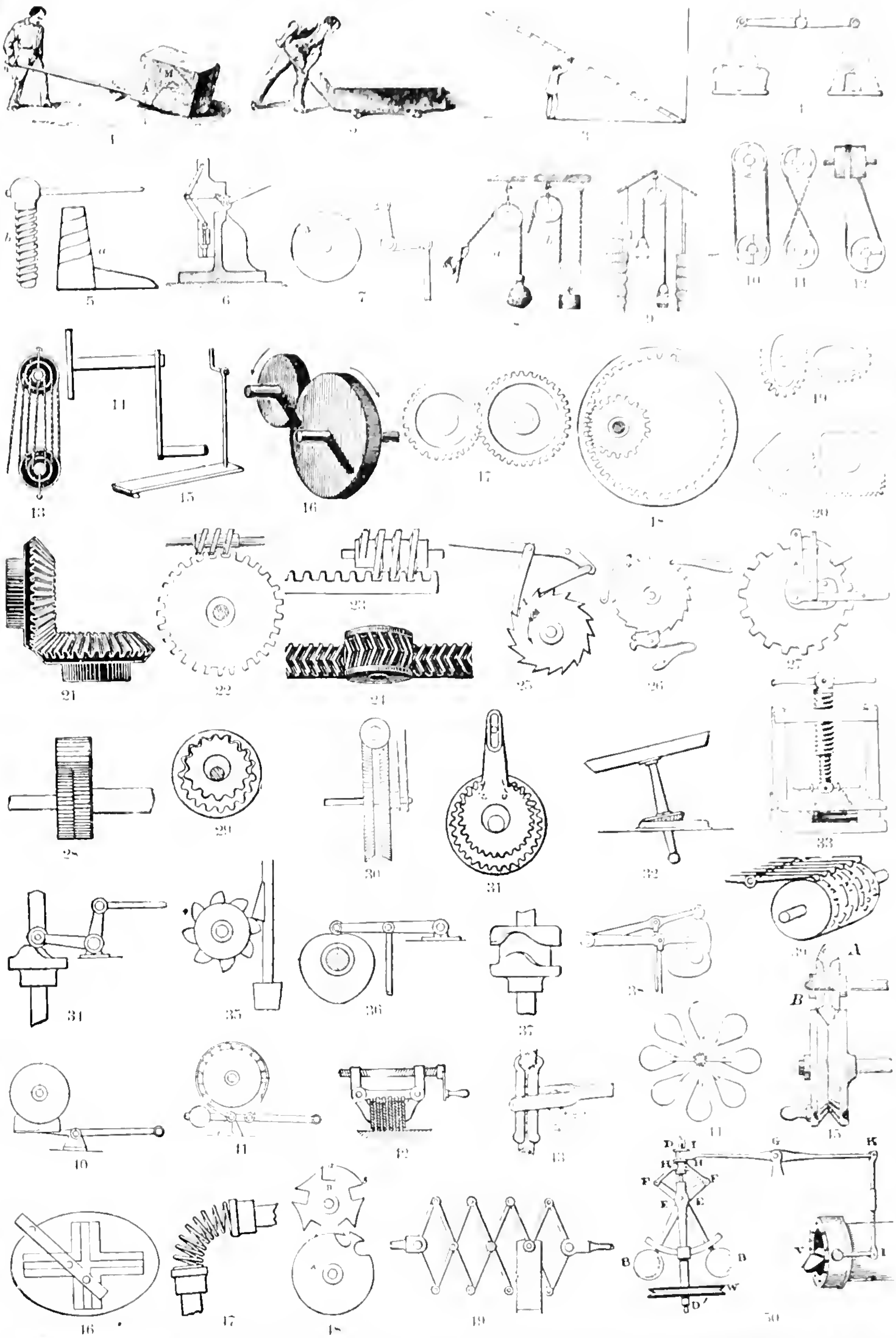
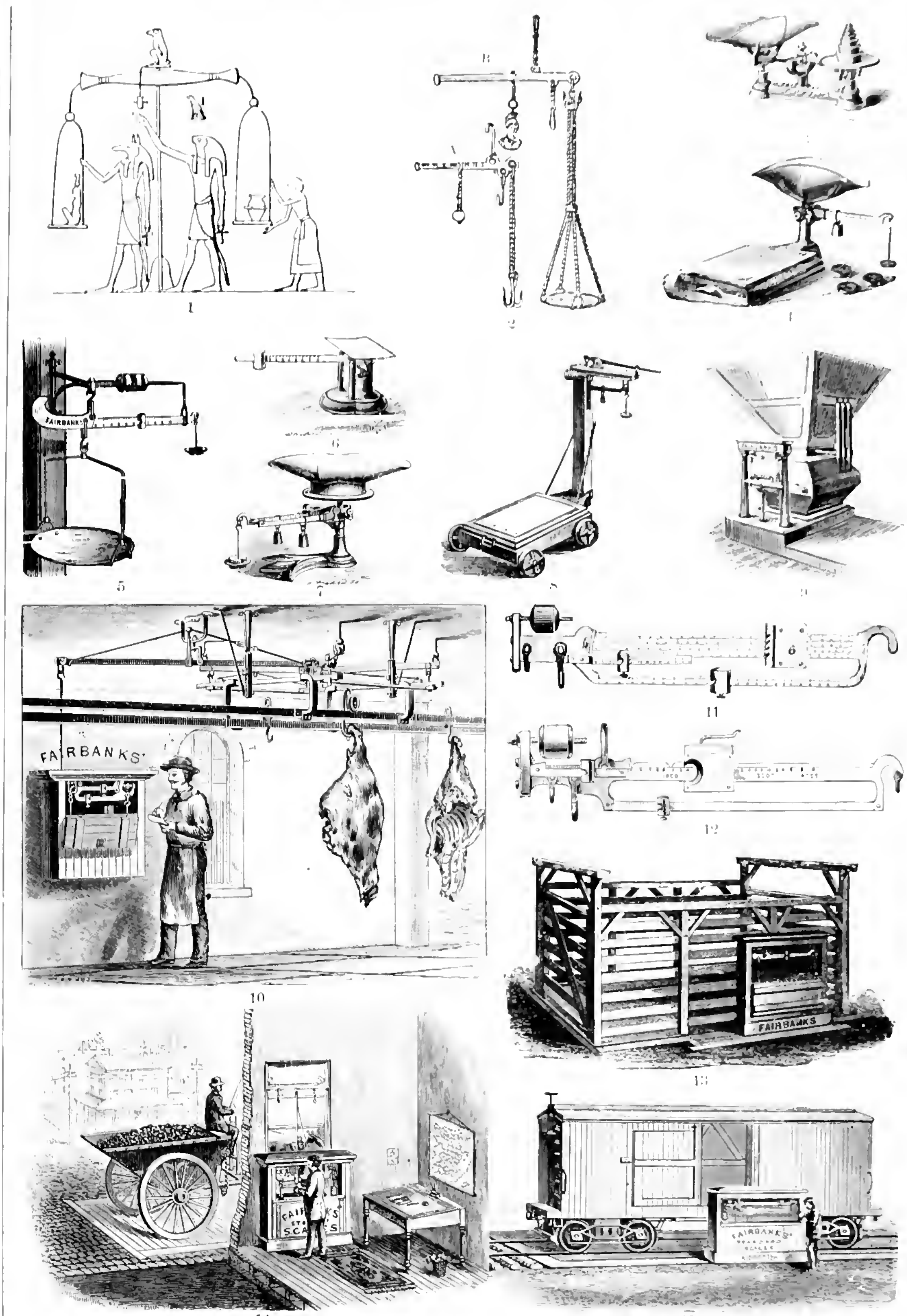


7

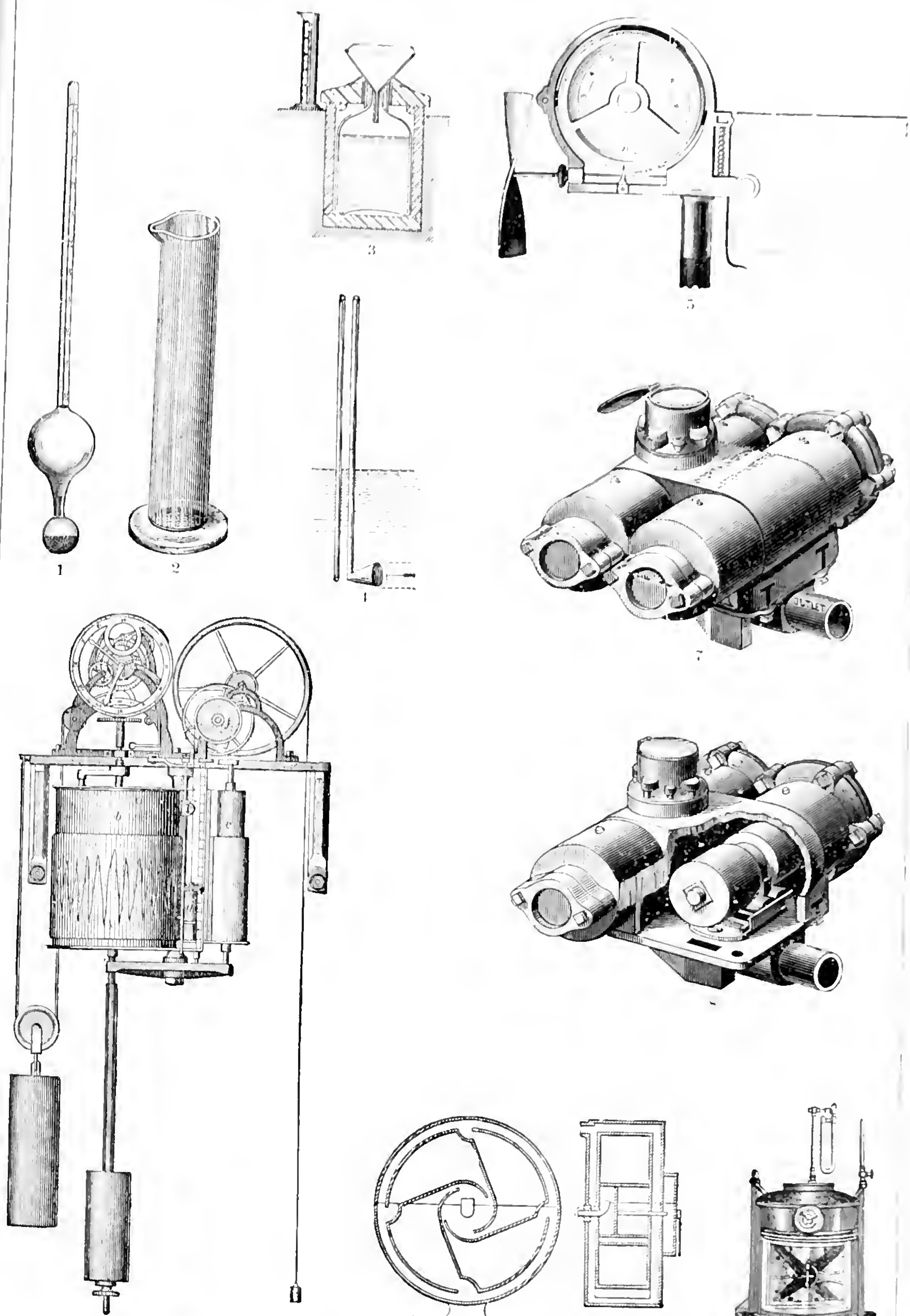
1. Eastern method of raising water from wells with rope and vessel [illegible] 2. La[illegible] [illegible] transport machine. 3. Italian water raising device. 4. Plan, 5. Elevation, of single belt transmission. 6. Plan, 7. Elevation, of single belt transmission, driving two shafts at right angles. 8, 9. Principle of hy[illegible] transmission.



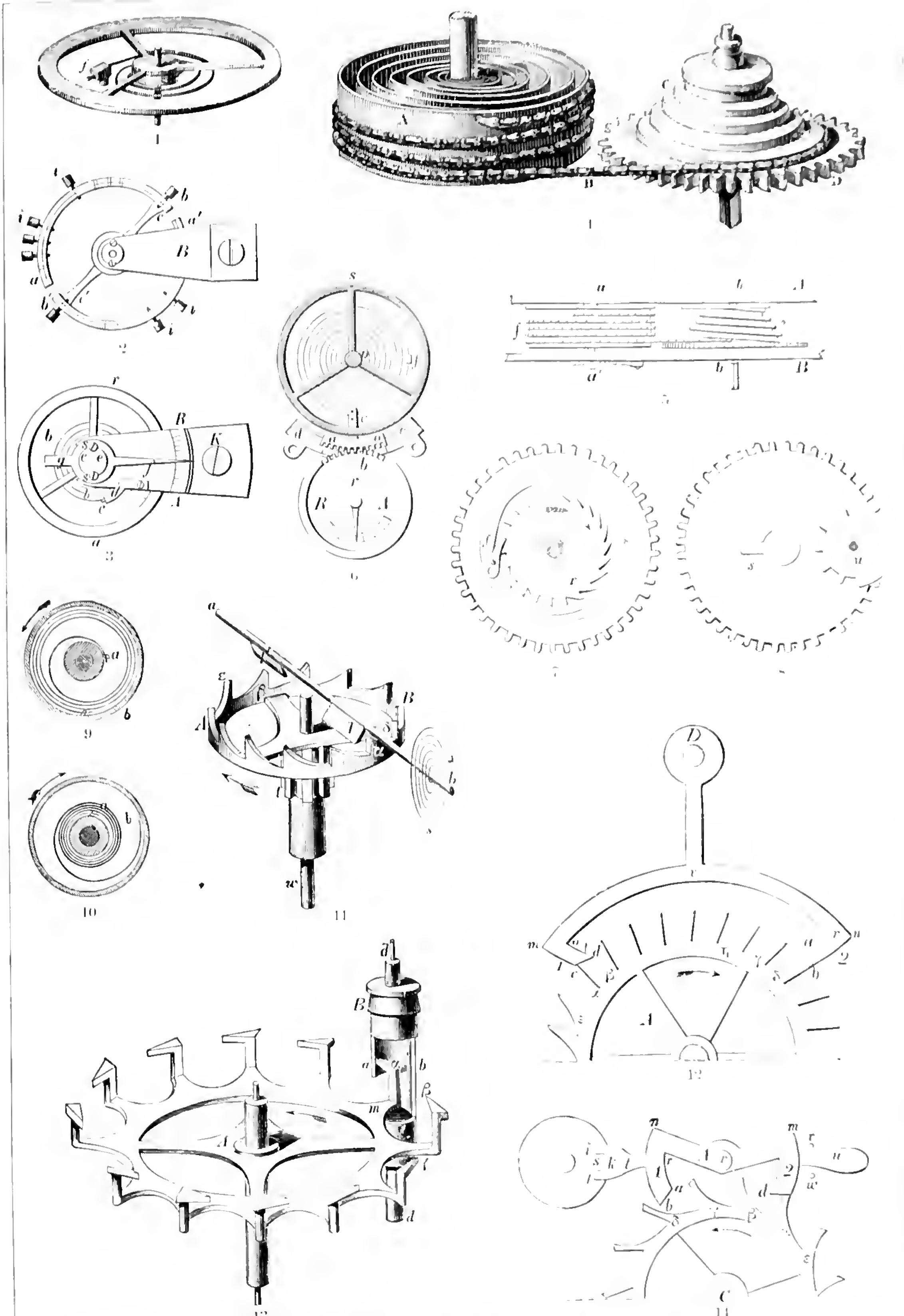
1. Prying-lever, or lever of the first kind. 2. Lifting-lever, or lever of the second kind. [illegible] beam. 5a. Principle of the screw. 5b. Screw and lever. [illegible] toggle. [illegible] Single fixed pulley combined with a movable pulley. [illegible] Balance [illegible] Single [illegible] belt. 12. Crossed-belt pulleys with axes at different angles. [illegible] White's [illegible] friction-rollers. 17. Spur-gear. 18. Annular gear. [illegible] Elliptic [illegible] wheels [illegible] or worm-gear. 23. Screw and rack. 24. Rack and pinion with [illegible] Ratchets [illegible] 28, 29. Differential gears. 30. Differential registering device. [illegible] 34. Side-face or crown cam. 35. Drop or stamp-mill cam. [illegible] rods. 39. Barrel-motion. 40. Shoe-and-lever brake. 41. Strap and lever brake. 42. [illegible] 45. Howlett's friction gear. 46. Ellipse trammel. 47. Flexible angle coupling. 48. Geneva stop. 49. Lazy tongs. [illegible] Governor.



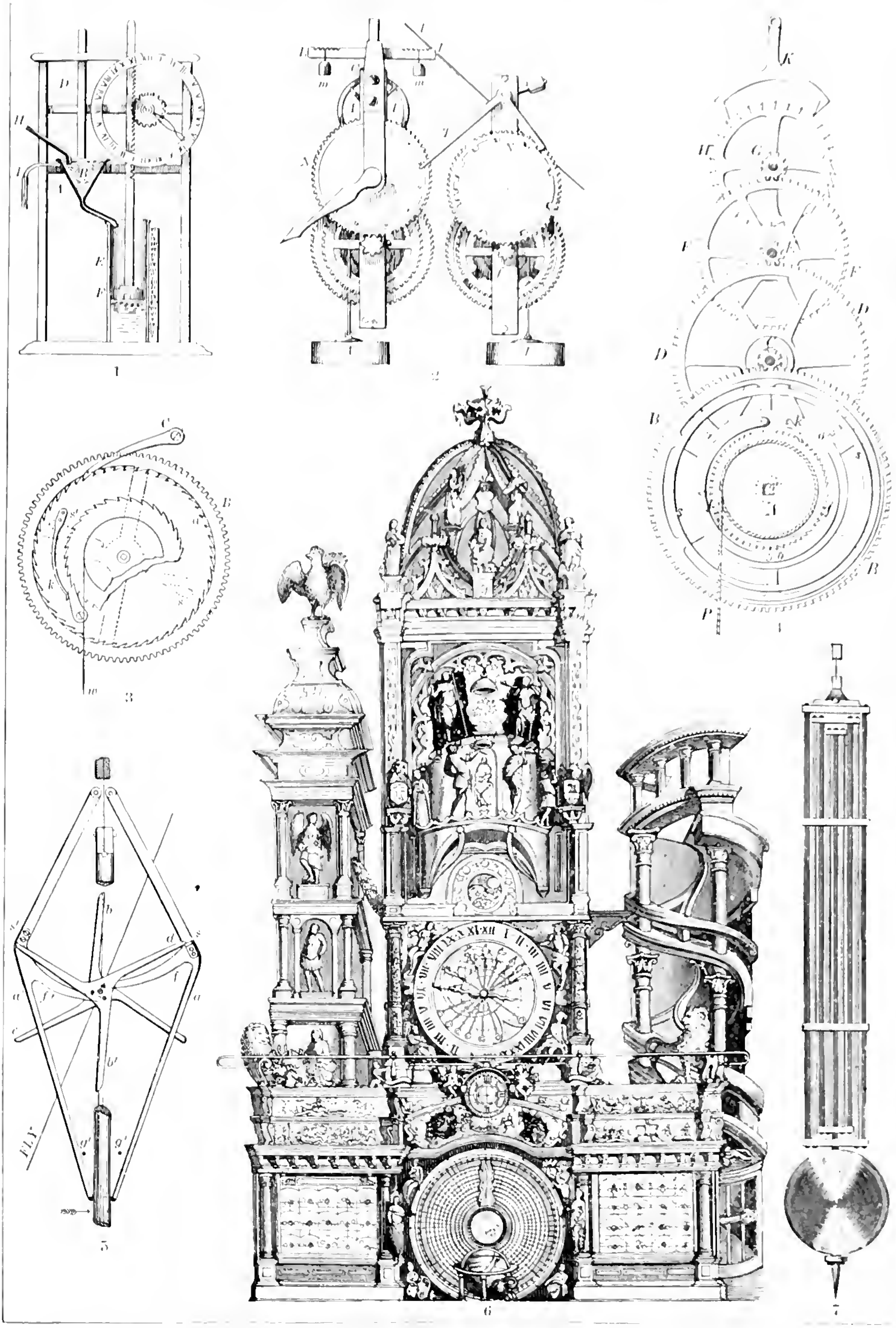
MEASUREMENT OF SOLIDS:—1. Ancient Egyptian balance. 2. Roman steelyards (at [illegible]). 3. Even-balance with weights, 4. Union or family scale, 5. Single-beam market-scale, 6. U. S. standard letter-scale, 7. Grocer's scale, 8. Portable platform scale, 9. Hopper scale for grain, 10. Standard abattoir scale, 11. Combination grain-beam, 12. Compound beam for hay scales, 13. Stock scale, 14. Coal dealer's scale, 15. Railroad track scale (E. & T. Fairbanks & Co., St. Johnsbury, Vt.).



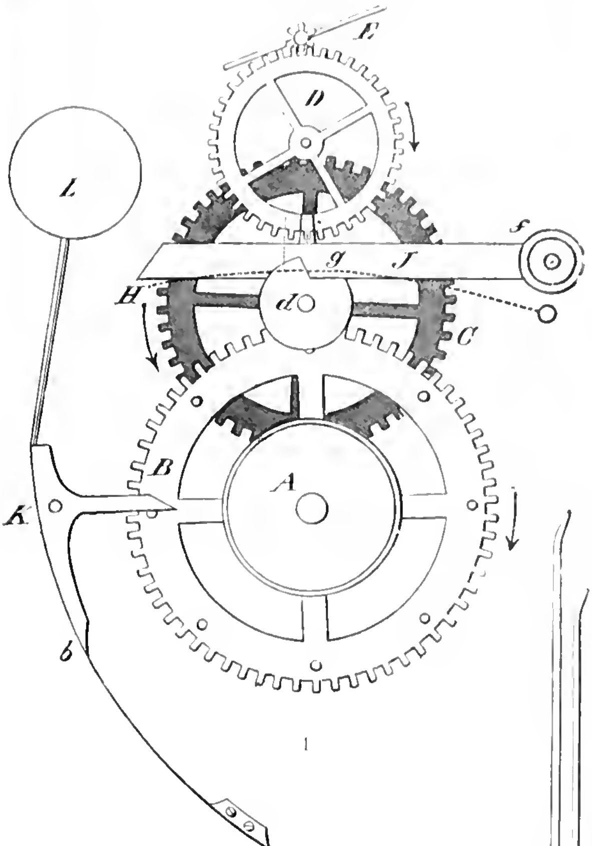
MEASUREMENT OF LIQUIDS AND GASES: 1. Hydrometer. 2. Hydrometer jar (Queen & Co., Philadelphia). 3. Rain gauge. 4. Pitot's tube. 5. Current meter (Queen & Co.). 6. Thomson's tide-gauge. 7, 8. Worthington's water-meter. 9. Acting principle of a "wet" gas-meter. 10. Gas-burner test-meter.



MEASUREMENT OF TIME:—1. Balance of an ordinary watch. 2. Compensation watch balance. 3. Hair-spring, balance and regulation (new style). 4. Perspective, with retaining plates removed, 5. Elevation, of a watch-barrel and fusee. 6. Watch-barrel regulating device (old style). 7. Toothed main-spring barrel. 8. Stop-work. 9. Watch-barrel with main spring unwound. 10. Watch-barrel with main spring wound. 11. Verge or "crown-wheel" escapement. 12. Graham's "dead-beat" escapement. 13. Cylinder escapement. 14. Detached-lever escapement of a Jurgensen watch.



MEASUREMENT OF TIME:—1. Egyptian clepsydra (20? B. C.). 2. Turret-clock of Heinrich von Wick, or De Vick (A. D. 1370). 3. Harrison's maintaining power as attached to weight clocks. 4. Train of a pendulum clock. 5. Denison's double three legged gravity escapement. 6. Great clock of the Strasburg Cathedral. 7. Compensated clock pendulum.



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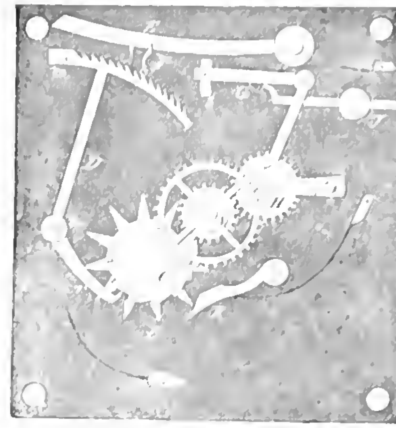

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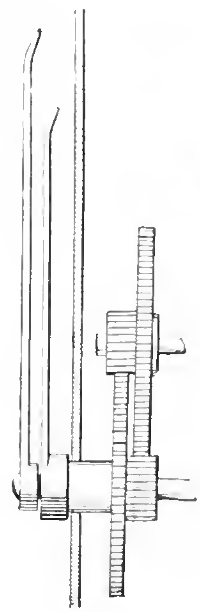

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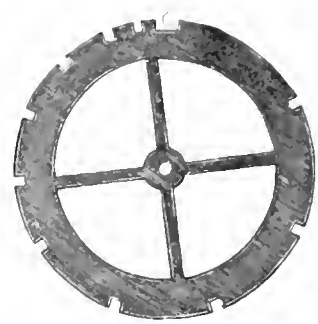

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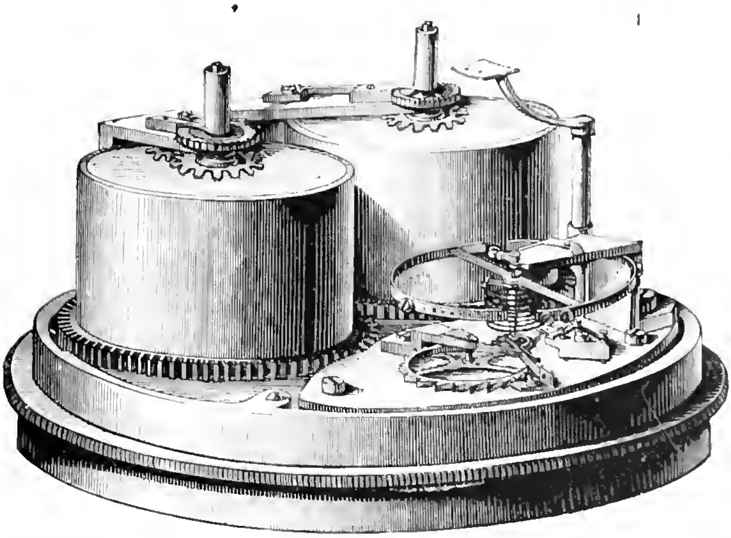

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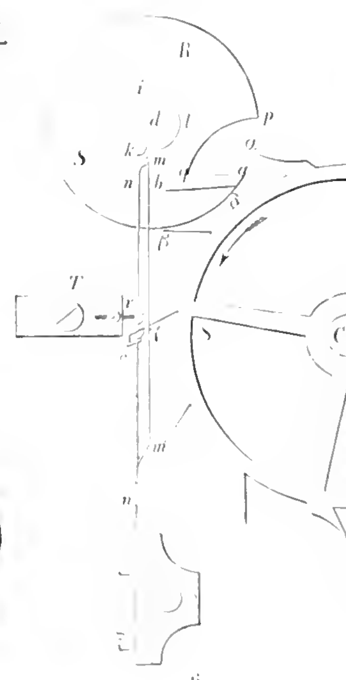

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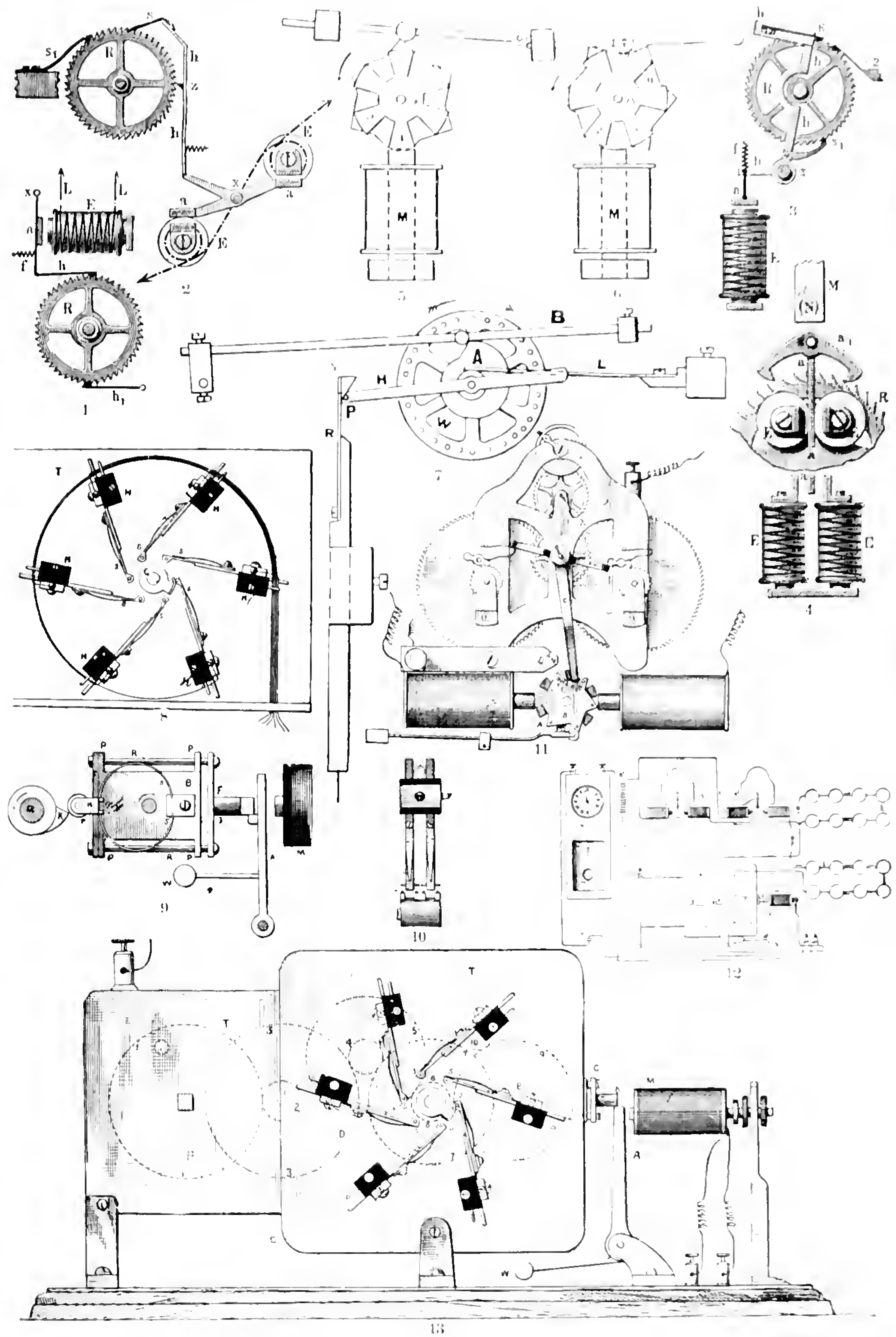
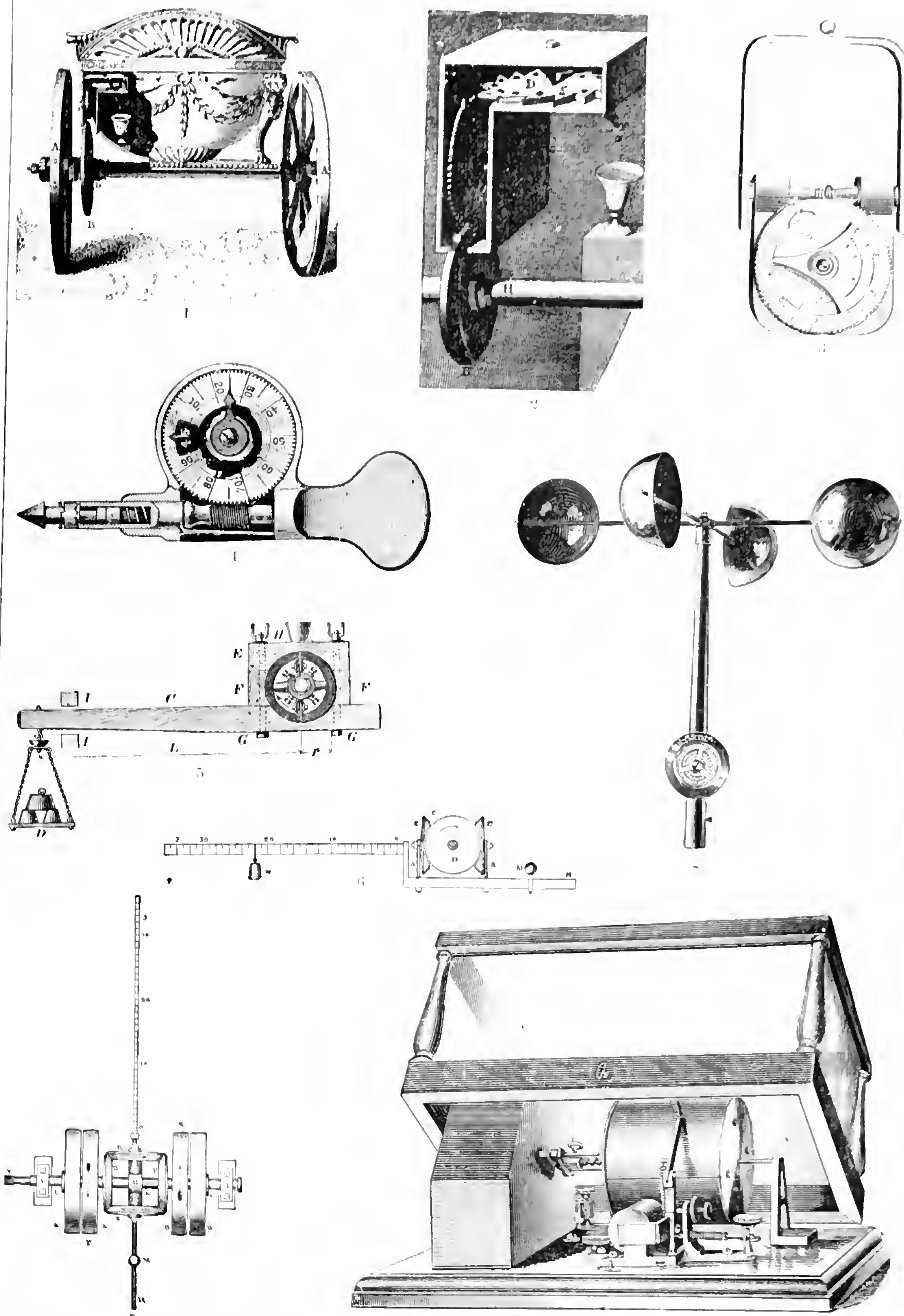
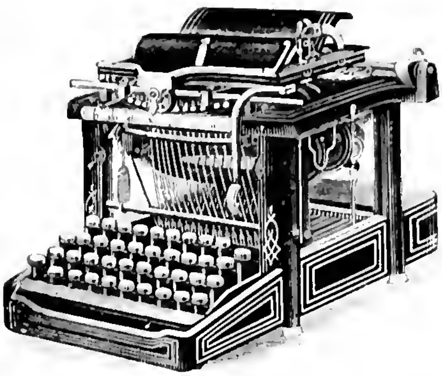
MEASUREMENT OF TIME: —1. Striking work, 2. Locking-plate, of a locking-plate striking-clock. 3. Striking work of a repeating striking-clock. 4. Motion work of a timepiece. 5. Marine chronometer. 6. Earnshaw's chronometer escapement.



MEASUREMENT OF TIME.—1. Bain's electric clock. 2. Siemens & Halske's electric clock. 3. Garnier's electric clock. 4. Stöhrer's electric clock. 5, 6. Spellier's electro-magnetic escapement. 7. Spellier's electric contact-maker with power accumulator. 8. Contact. 9. Locking mechanism. 10. Contact spring. 11. Sentinel. 12. Plan of general distribution. 13. Time-distributor, of Spellier's time distribution for electric clocks (Louis H. Spellier).



MEASUREMENT OF SPACE AND MOTION.—1, 2. Ancient odometer (according to Vitruvius). 3. M[illegible] (Queen & Co., Philadelphia). 4. Tabor speed-indicator. 5. Prony dynamometer. 6, 7. Batch[illegible] dynamometer. 8. Anemometer of the U. S. Signal Service. 9. Anemometer recording apparatus (Queen & Co.).



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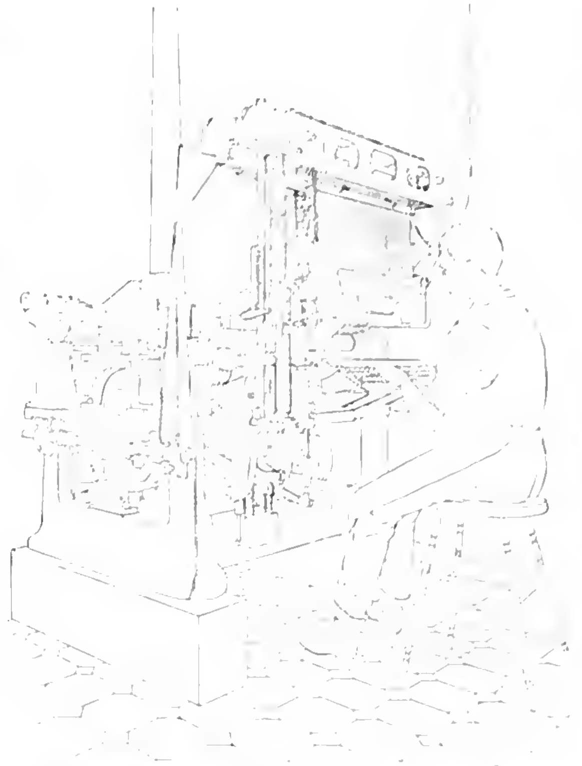

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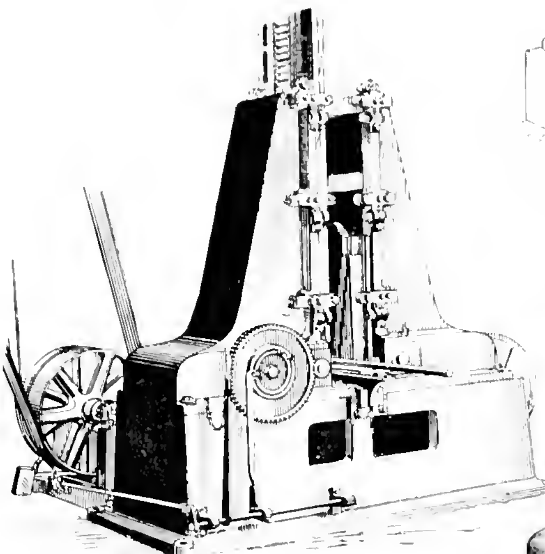

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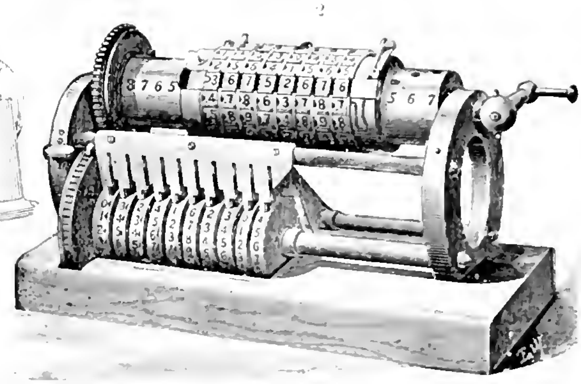

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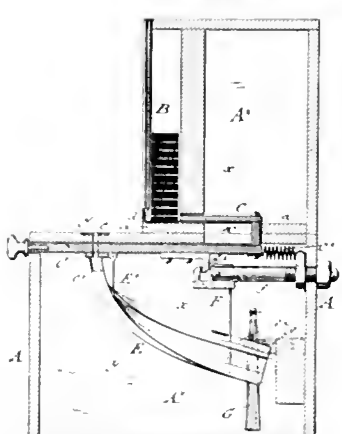

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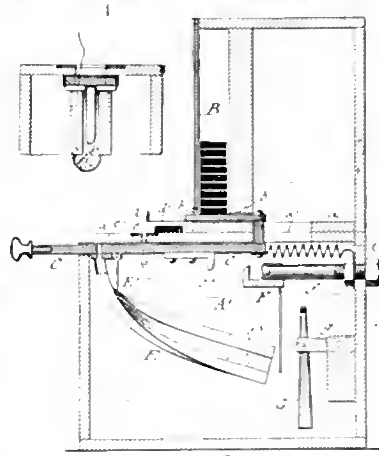

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1. Remington typewriter. 2. "Linotype" or type-setting machine. 3. Simonds's metal-working machine. 4. Calculating machine. 5. Egyptian lustral vase (according to Hero). 6, 7. Nickel-in-the-slot-machine (lengthwise vertical sections).

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TECHNOLOGY.

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TO

MOTORS, TRANSPORT AND MEASURING MACHINES.